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The Electrical Researches of the Hon. Henry Cavendish, F. R. S.

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THE work of Cavendish is familiar to all of us through two celebrated experiments, the Cavendish experiment for determining the gravitational constant and his proof of the inverse square law for electrical charges. Both of these experiments have been repeated many times since Cavendish's original work, and it is largely through these repetitions that we have come to know them. But these experiments represent only a small fraction of the scientific work that Cavendish carried out. Had all of his work been made available to the scientific world during his lifetime, undoubtedly scientific history would have been markedly different. As it was, Cavendish left nearly all his electrical researches in the form of notes and they were not published until nearly a century later.

Henry Cavendish was born at Nice in 1731 and matriculated into Peterhouse College, Cambridge, in 1749, leaving early in 1753 without proceeding to a degree. He appears at once to have thrown himself energetically into scientific work, chiefly of a chemical nature, and was elected a Fellow of the Royal Society in 1760. His electrical researches occupied the years 1771–1781, and though he lived until 1810, he published but two papers on electricity. The remainder of his work was edited by Maxwell and published by the Cambridge University Press[1] in 1879. Maxwell considered this work of sufficient importance to give continual application to the task during the last five years of his life.

Cavendish, though a man of considerable wealth, formed early in life the habits of economy and the peculiar oddities of character that he exhibited later in life to such a striking degree. His peculiar reticence in both social and scientific affairs, together with his great aversion to any form of controversy, may account for his lack of interest in publishing his electrical researches.[2]

It appears that Cavendish was the first person to appreciate the distinction between quantity of charge and potential or "degree of electrification" as he called it. Accordingly, he shows that if two charged conductors are connected by a wire, they have the same "degree of electrification," and he spends considerable time and effort on determining the ratio of charges on objects that have the same "degree of electrification." His method was essentially to compare the charge on a conductor with that on a sphere 12.1 in. in diameter when both were at the same potential. Since he had proved that the charges on similar conductors are proportional to their linear dimensions, he stated his results in terms of the diameter of a sphere which had the same charge and potential, that is, the same capacitance as the conductor being investigated. The capacitance of an object is therefore stated

[1] A second edition was published by the Cambridge University Press in 1921 under the editorship of Sir Joseph Larmor.

[2] See G. Wilson, *The Life of the Hon. Henry Cavendish* (Cavendish Society, 1851).

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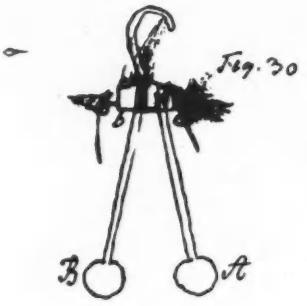


FIG. 1. Diagram of Cavendish's electroscope, reproduced from his notes.

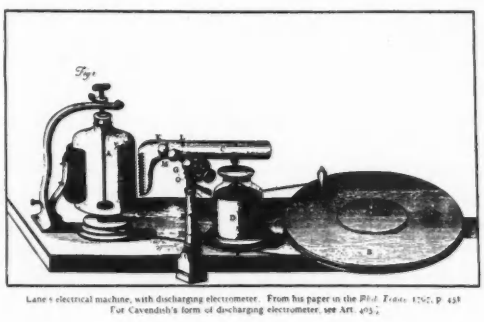
by Cavendish in "globular inches" or often in "inches of electricity." Since the capacitance of an isolated sphere is numerically equal to its radius, Cavendish's results may be readily expressed in modern units.

An example from Cavendish's notes will serve to illustrate his experimental procedure for determining the ratio of the capacitances of two condensers. The electroscope, a pair of pith balls, used for measuring charges or potentials is very crude as is shown in Fig. 1. It can be readily appreciated that with such rough apparatus, only very careful observations would give reliable results. The electrostatic machine for charging the condensers is shown in Fig. 2. A condenser and electroscope were first charged by the machine and the separation of the pith balls noted. This charge was then shared with a similar but uncharged condenser, thus halving the potential of the system. The separation of the pith balls was again noted. In this manner, Cavendish calibrated his electroscope for two potentials, the one double the value of the other. A condenser, whose capacitance was known in terms of the diameter of an equivalent sphere, was charged until the pith balls separated the required amount. The charge on this condenser was then shared with a small uncharged condenser whose capacitance was required, the process being repeated until the potential of the system was reduced to one-half its original value as shown by the pith balls. After each sharing of charge, the small condenser was, of course, discharged. In a particular experiment, Cavendish found it necessary to repeat this operation between 11 and 12 times, or $11\frac{1}{4}$ as he estimated it. If C and c represent the capacitances of the two condensers, then

$$\left(\frac{C+c}{C}\right)^{11\frac{1}{4}}=2, \quad \text{or} \quad \frac{c}{C}=11\tfrac{1}{4}\sqrt{2}-1.$$

Cavendish's large condensers were made from glass jars, the outer sides of which were coated with tinfoil, and because of the difficulty of coating the insides, he filled them to the required amount with a salt solution. A wire placed inside made the necessary electrical connection. A battery made from a number of such jars was found by Cavendish to contain 481,000 in. of electricity, which means the battery had a capacitance of approximately 0.7 μf. The accuracy which Cavendish attained in his experiments may be illustrated by his experimental value, 1/1.57, for the capacitance of an isolated circular disk in terms of a sphere of the same diameter. The calculated ratio of these is $2/\pi$ or 1/1.571.

In experimenting on condensers made with



Lane's electrical machine, with discharging electrometer. From his paper in the *Phil. Trans.* 1767, p. 458. For Cavendish's form of discharging electrometer, see Art. 403.

FIG. 2. Electrostatic machine.

glass or other insulators between conducting plates, Cavendish found the charges on them several times greater than those calculated for similar condensers with air as insulator. In this manner, he discovered and measured the dielectric constant for several substances. The values he found are 8.2 for plate glass, 8.5 for crown glass, and 4.5 for shellac.

Cavendish carried out experiments to determine whether the capacitance of a condenser depends on the potential to which it is raised or, as he expresses it, "whether the charge of a

coated plate bears the same proportion to that of a simple conductor whether the electrification is strong or weak." His results show, within experimental error, no dependence of capacitance on potential, or, as it might be stated now, that the electric induction is proportional to the field strength. Corrections were estimated and made for the creeping of charges around the edge of the conductors mounted on insulators, and all experiments were carried out as rapidly as possible to avoid dielectric absorption.

Another series of experiments dealt with the relative resistances of substances. This investigation was made before any source of steady potential was known, so we find Cavendish using as his source charged condensers. These were discharged through a conductor in series with his body, his estimate of the shock produced being his galvanometer. His method of comparing resistances was to adjust the resistance of one conductor until the shock received by the discharge of a condenser through it was equal to that received by the discharge of a similar condenser through the other conductor. Most of his experiments were made with conducting solutions placed in glass tubes.

In one experiment, Cavendish took two glass tubes whose areas of cross section were in the ratio of 250 to 44, and these he filled with salt solution of the same concentration. Six similar condensers were charged to the same potential and were used to send a discharge through first one tube and then the other, the lengths of the salt solution being adjusted until the shock felt through either was the same. The same shock was found when the discharge was sent through $44\frac{1}{4}$ in. of the large tube and 6.8 in. of the small tube. Now $6.8/44\frac{1}{4} = (44/250)^{1.08}$ and Cavendish concludes that the "resistance should seem as the 1.08-power of the velocity." Other experiments gave 1.03, 0.98, and 1.00, and we shall assume the value 1.00 correct for purposes of illustration.

In order to understand Cavendish's results, we must note that he used the term "velocity" in the sense that we use *current per unit area* today. If we let l_1 and A_1 represent the length and area of cross section of one tube and l_2 and A_2 the corresponding quantities for the other tube, Cavendish's results may be written $l_1 I/A_1 = l_2 I/A_2$, or $lI/A = \text{constant}$. This is essentially Ohm's law, which law was announced some fifty years after these experiments.

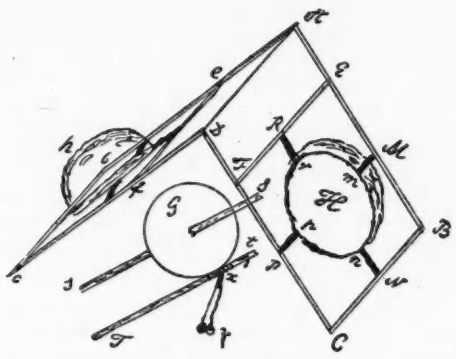


FIG. 3. Sketch of apparatus for determining the variation of force with distance between charges, from Cavendish's notes.

In another series of experiments on the relative resistances of various salts and acids in water solutions, Cavendish arranged "that the quantity of acid in each should be equivalent to that in a solution of salt in 29 of water." (This means that the concentration was one part of salt to 29 of water by weight.) The remarkable thing is that Cavendish must have been familiar with equivalent weights, though where he obtained this important information other than from his own private researches is not known. This series of experiments, which serve to illustrate Cavendish's insight into many physical phenomena, was carried out purely for his own satisfaction. We find him attempting to determine the physical factors that determine the strength of an electric shock, though he apparently was unable to satisfy himself on this point.

A third series of experiments which we will mention are those on the determination of the law of force for electrical charges. Cavendish says:

> "I took a globe 12.1 inches in diameter, and suspended it by a solid stick of glass run through the middle of it as an axis, and covered with sealing wax to make it a more perfect non-conductor of electricity. I then inclosed this globe between two hollow pasteboard hemispheres, 13.3 inches in diameter, and about 1/20 of an inch thick, in such manner that there could hardly be less than 4/10 of an inch distance between the globe and the inner surface of the hemispheres in any part, the two hemispheres being applied

to each other so as to form a complete sphere, and the edges made to fit as close as possible, notches being cut in each of them so as to form holes for a stick of glass to pass through. [Fig. 3]

"By this means I had an inner globe included within an hollow globe in such manner that there was no communication by which the electricity could pass from one to the other.

"I then made a communication between them by a piece of wire run through one of the hemispheres and touching the inner globe, a piece of silk string being fastened to the end of the wire, by which I could draw it out at pleasure.

"Having done this I electrified the hemispheres by means of a wire communicating to the positive side of a Leyden vial, and then, having withdrawn this wire, immediately drew out the wire which made a communication between the inner globe and outer one, which, as it was drawn away by a silk string, could not discharge the electricity either of the globe or hemispheres. I then instantly separated the two hemispheres, taking care in doing it that they should not touch the inner globe, and applied a pair of small pith balls, suspended by fine linen threads, to the inner globe, to see whether it was at all over or undercharged. . . .

"The inner globe and hemispheres were also both coated with tinfoil to make them the more perfect conductors of electricity. . . . The result was, that though the experiment was repeated several times, I could never perceive the pith balls to separate or shew any signs of electricity."

In order to test the sensitivity of the apparatus, Cavendish charged the Leyden vial to 1/60 of its previous amount and communicated this to the inner globe and found he could detect this amount with his pith balls. He concludes,

"It appears, therefore, that if a globe 12.1 inches in diameter is inclosed within a hollow globe 13.3 inches in diameter, and communicates with it by some conducting substance, and the whole is positively electrified, the quantity of redundant fluid lodged in the inner globe is certainly less than 1/60th of that lodged in the outer globe, and that there is no reason to think from any circumstance of the experiment that the inner globe is at all overcharged.

"Hence it follows that the electric attraction and repulsion must be inversely as the square of the distance, and that when a globe is positively electrified, the redundant fluid is lodged entirely on its surface."

Cavendish proceeds then to determine how the force between two equally charged pith balls varies with the amount of charge on each, or as he expresses it, "Whether the force with which two bodies repel is as the square of the redundant

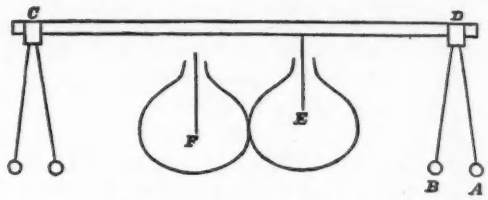


FIG. 4. Apparatus for determining how the force varies with the charge, from Cavendish's notes.

fluid, tried by straw electrometers." In the apparatus used (Fig. 4), *CD* represents a wooden rod 43 in. long covered with tinfoil, and at *C* and *D* are suspended pith ball electrometers. By placing wires on the ends of pith balls *A* and *B*, Cavendish made this electrometer 1/4th as sensitive as the one at *C*. At *E* and *F* are two similar Leyden jars. The Leyden jar *E*, connected with the rod *CD*, was then charged and the separation of the pith balls *A* and *B* noted. The Leyden jar *F*, which was uncharged, was now connected into the circuit so that the effective potential of the system was halved, the capacitance of the rod and electrometers being negligible compared to that of the Leyden jars. It was then found that the pith balls of the electrometer at *C* separated the same amount as did the pith balls *A* and *B* before the sharing of the charge. From this, it follows that the force between two equally charged objects varies as the square of the charge on either object, since by halving the charges, keeping the distance the same, the force is reduced to one fourth its previous value.

It is interesting to note here that Joseph Priestley in his book, *The History and Present State of Electricity with Original Experiments*, published in 1769, had come to the conclusion that the force between electrical charges varies inversely as the square of the distance. Priestley says, "May we not infer from this experiment [absence of electrification within an electrified cup] that the attraction of electricity is subject to the same laws with that of gravitation and is therefore according to the squares of the distances; since it is easily demonstrated that were the earth in the form of a shell, a body in the inside of it would not be attracted to one side of it more than another."

A Simple Test for the Preciseness of a Definition of a Physical Term or Quantity

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DEFINITIONS of physical terms and quantities are treated quite differently by different authors of elementary physics texts. Some shun definitions almost entirely by giving illustrative statements regarding the quantity under consideration and then stating the appropriate name. While the statements are generally true, they are not in the form of definitions nor would one mistake them as such. To illustrate:

> When one considers a given machine for a specific purpose, he wishes to know, among other things, how much work may be performed with its aid when a given amount of energy is supplied to it. This information is described by what is known as the *efficiency* of the machine.

On the other hand, some writers habitually present definitions whenever new terms are introduced. Others range between these extremes, with the tendency more toward the latter group than the former. Presumably authors of the first group would say that they "teach physics, not definitions," whereas those of the second group would say that "clear concepts go hand in hand with precise definitions."

In his consideration of each new college physics textbook as a possible text for class use, the author of the present paper has given special attention to definitions. Many have been found that are interesting and excellent, as well as many that are interesting but not so excellent. Of the latter, the frequency of appearance has seemed so great as to justify special attention.

In this paper, we present a simple test for the preciseness of a definition,[1] its application to some specimens taken from several commonly used texts, and a plan for correcting what seems a rather unsatisfactory state of affairs. Though we here discuss principally certain quantitative features, we clearly realize that those which are qualitative may be equally or even more basic to clear understandings.

[1] Exact precision may sometimes demand an undue amount of detail. In such instances second-order inaccuracies may reasonably be overlooked, but hardly is that the case with first-order inaccuracies. Those under consideration here belong to the first-order group.

It seems best, at the start, to define the phrase "the definition of a term or quantity." Of course, what is meant may be expressed variously. As one most suitable for the purpose at hand, we propose the following statement, since within itself it contains an important criterion of a good definition: *A definition of a term or quantity is an expression stated in simpler or more fundamental terms or quantities that may replace the original term or quantity wherever used without loss or change of thought.*

Let us apply this criterion of interchangeability to the following simple sentences:

(a) The speed is 10 cm/sec.
(b) The pressure experienced was 50 cm-of-mercury.
(c) The heat of vaporization of water at 100°C and a pressure of 1A is 540 cal./g.

On replacing the terms by their definitions, we have:

(a′) The time rate of change of position is 10 cm/sec.
(b′) The ratio of the force experienced normal to an element of area to the area of that element was 50 cm-of-mercury.
(c′) The ratio of the heat supplied for the vaporization of water without change of temperature at 100°C and a pressure of 1A to the mass of water vaporized is 540 cal./g.

It is agreed that the substitution of the definition for the term has resulted in some awkwardness of English, but what is of interest is that the terms and the definitions are really interchangeable.

If we look at a definition mathematically, we find that it takes the form

$$X = Y,$$

where X stands for the term or quantity being defined, Y for the definition, and the equality sign for the connecting word "is." As a corollary, it follows that, for any case where a quantity of known magnitude is discussed, the precise answers to the two questions "What is X?" and "What is Y?" must be *identical*. In case c, c′ above, this means that the same answer must be given to the two questions "What is the heat of

vaporization of water at 100°C and 1A" and "What is the ratio for water of the heat supplied without change of temperature at 100°C and 1A to the mass vaporized." It is, in each instance, 540 cal./g. It is to be emphasized that besides this X, Y-test, there are other tests for the quality of a definition, which, however, we shall not go into here.

From ten well-known general physics texts the writer has selected the following definitions for the application of the X, Y-test. The words in square brackets represent additions required by the removal of the statements from their contexts.

(1) An impulse may be expressed by the total change of momentum which it imparts to any free mass upon which it acts.

(2) The mass of a unit volume of any material is its density.

(3) The theoretical mechanical advantage of a simple machine is the theoretical ratio of the force the machine will produce or overcome to the force supplied to it.

(4) The surface tension of a liquid is the force with which the surface on one side of a line one centimeter long pulls against that on the other side of the line.

(5) The specific heat is the amount of heat in calories necessary to raise one gram of a substance 1° C.

(6) The thermal capacity of a body came to be defined as the number of heat units required to raise the temperature of the body through one degree.

(7) The temperature above which it is impossible to liquefy a gas by any pressure however great is called the critical temperature of that gas.

(8) [The specific resistance or resistivity of any material] is the resistance of a wire [of that material] 1 cm long and of 1 sq. cm area.

(9) The [electric] intensity or the [electric] field strength at any point is the force exerted on a unit positive charge placed at the point.

(10) The work done on a unit pole as it goes about the closed path [around a wire carrying a current] is called the magnetomotive force of the path.

That in some of these statements the name of the quantity appears at the end, and that in some the preferred word "is" is replaced by the longer phrase "may be expressed," etc., is considered inconsequential.

Let us apply the test of interchangeability. Answers that might be given to the questions "What is X?" and "What is Y?" for imagined cases involving the ten definitions are given in Table I. If one has faith in the X, Y-test, he must conclude that of the ten definitions only No. 1 and possibly No. 3 are precise. A similar lack of precision, as judged by this test, is characteristic of a large fraction of the definitions in a majority of the books investigated. On the other hand, there are two or three texts which, judged by the same test, are generally precise.

TABLE I. *Answers that might be given in applying the X, Y-test of interchangeability to the ten definitions given in the text.*

DEFINITION	POSSIBLE ANSWER TO "WHAT IS X?"	CORRESPONDING POSSIBLE ANSWER TO "WHAT IS Y?"
(1)	10 g cm/sec. or 10 dy sec.	10 g cm/sec. or 10 dy sec.
(2)	10 g/cm³ or 10 mg/mm³	10 g or 10 mg
(3)	85 percent	Depends on the meaning of "theoretical ratio"
(4)	70 dy/cm	70 dy
(5)	0.8 cal./g C°	0.8 cal.
(6)	300 cal./C°	300 if the cal. and the C° are assumed
(7)	365°C	Any temperature above 365°C
(8)	20 μ-ohm cm	20 μ-ohm
(9)	20 dy/unit Es charge or, better, 20 dy/escoulomb	20 dy, if the escoulomb is chosen
(10)	10 gilberts, or 10 erg/unit mag. pole	10 ergs

Some textbook definitions err by the accidental omission of a word or phrase, as illustrated by the absence of the word "lowest" before "temperature" in No. 7; this error is not always easy to avoid. Some, as is the case with No. 6, are so worded that the quantity defined seems to be a numeric rather than a physical quantity measurable in physical units. Most of the definitions that are wrong, however, err in characterizing a quantity by a single simple unit, whereas in reality it is characterized by a compound unit of which the single unit is a part. Numbers 2, 4, 5, 8, 9, and 10 are of this type.

In view of the prevalence of the last type of error, it is strange that no one, so far as the writer knows, has erroneously defined the speed of a body consistently with their other definitions as "the distance that the body travels in a unit of time." It is also strange that consistently, so very few or none define the Young's modulus for a substance in accord with the equation $M=FL/al$, as "the force which applied to a wire of unit cross section will double its length" or "the length of a wire of unit cross section of that substance which will be stretched a unit of length by a unit of force."

As physicists and as teachers, we take pride in physics as an exact science. We preach it to the students. We desire them to get clear and precise ideas regarding the phenomena they study. As teachers, the only thing that pleases us more than to have our students discuss the material studied with a clear and precise understanding, is to have them independently forge ahead into new fields or delve more deeply into old fields. Why then do we encourage looseness of expression by using definitions which imply that densities may be measured in grams, surface tensions in dynes, specific heats in calories, resistivities in micro-ohms, field strengths in dynes, and magnetomotive forces in ergs?

It is argued that sometimes a formal, precise definition is too abstract for the ordinary student. Of the definition by itself this is probably often true. The remedy is not lack of precision, but more explanation. Whether or not certain terms should be defined is a matter of opinion. But, if one decides to present a definition, it should be precise and, if necessary, it should be accompanied by an explanation. Thus, concerning surface tension we may say, following an assumed derivation of the equation $S = F/l$:

> The surface tension of a liquid[2] is the ratio of the force with which that portion of a surface layer of the liquid on one side of a straight line drawn in the surface layer acts on the portion of the layer on the other side of the line, to the length of that line. For water whose surface tension at 20°C is about 73 dy/cm, this means that the portion of a surface layer of water on one side of a straight line in the surface of 1 cm length attracts the water in the surface layer on the other side of the line with a force of 73 dynes.

Though they may not understand the definition, even rather slow students will not mistake such an explanatory sentence for one. Nor will the instructor feel it necessary to apologize to the brighter students for a definition that is not what it should be.

This tendency toward inaccuracy in physics texts is naturally accompanied by another tendency which some regard as equally if not more serious. Many authors are consistently careless with regard to the units used in expressing the values of measured physical quantities. Altogether too often we see or hear surface tensions, field strengths, pressures, and the universal gravitational constant all expressed in terms of the common force unit, the dyne; specific heats, heat of fusion and vaporization, and the universal gas constant expressed in calories; resistivities in micro-ohms, potentials in ergs, and energies and velocities in volts. This tendency will disappear, if ever, only with the disappearance of the tendency to state definitions carelessly.

In summarizing, the writer asserts that a most valuable and needed test for definitions to be used in physics is the interchangeability test which demands precisely the same answers to the two questions, "What is X?" and "What is Y?" where X stands for the quantity defined, and Y for the definition; that, if the definition of a quantity as precisely stated is too abstract for the average student, the definition should be either omitted or accompanied by a lucid explanation of its meaning; and that, for the sake of the instructor, if none other, who has now occasionally to apologize for his text, textbook writers generally should treat definitions with greater care. Consistency and accuracy are expensive of time and effort, but they yield great comfort and satisfaction.

[2] More precisely, this is the surface tension of an interfacial layer between the liquid and the atmosphere. This may be considered to be a second-order correction, however.

Annual Business Meeting of the Kentucky Chapter

THE annual business meeting of the Kentucky Chapter of the American Association of Physics Teachers was held at Centre College on January 15. The entire session was devoted to the conduct of business and to informal discussion of the purposes and policies of the Chapter. Officers were elected for 1938 as follows: *President*, A. D. Humwell, Eastern State Teachers College; *Vice president*, O. T. Koppius, University of Kentucky; *Representative on the Executive Committee of the American Association of Physics Teachers*, D. M. Bennett, University of Louisville.

Evaluation of Student Achievement in the Physical Sciences—The Application of Laws and Principles

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THE philosophy and point of view basic to evaluation has been described in a previous article.[1] The purpose of the present paper is to discuss in specific terms a meaning of the objective "application of laws and principles" and to indicate a way of obtaining evidence of student achievement in this objective.

In the unified course on physics and astronomy at Ohio State University, one of the aims of instruction is directed toward *the development of the students' ability to apply physical laws and principles in problem situations that have not previously been explained in the course of study.* This particular objective is emphasized by many teachers of the physical sciences and receives implicit recognition in many of the current physical science textbooks. Why is this objective considered to be of importance by these teachers? If there is any one outstanding purpose in the investigation of scientists, it is that of finding generalizations which afford common descriptions of large numbers of natural phenomena. The use of these generalizations has in the main been twofold: first, to make possible predictions with varying degrees of accuracy in those areas where the generalizations have application; second, to simplify the descriptions of many natural phenomena by interpreting them in terms of principles or generalizations.

When situations which involve the application of physical laws and principles are analyzed, they appear to fall into three classes:

(1) Numerical problems in which a substitution is made directly into a formula which expresses the generalization; this means that the student uses a formula in the solution of physical problems after he has developed an understanding of it through various experiences—laboratory, library, or lecture and discussion; for example, the student may be required to calculate the centripetal force that must be applied to an automobile of a given mass if it is to round a curve of a given radius with a certain speed.

(2) Problems in which an exact numerical solution is not required but in which a generalization is used to predict how one quantity will change when one or more related quantities are varied; for example, a student may apply the principles of centripetal force to deduce or predict the change in this force which results from an increase in the speed of an automobile which is moving in a circular path, or from a change in the curvature of the path when the speed remains constant.

(3) Phenomena for which the student is expected to recognize that a particular generalization or generalizations are basic for their explanation but for which neither an exact numerical solution as in *1* nor a qualitative prediction as in *2* are involved; for example, the student might be expected to recognize that the principles of centripetal force may be used to explain how an automobile is brought out of a skid when the front wheels are turned into the direction of the skid.

The person who will not be actively engaged in scientific work will usually apply generalizations in a manner indicated in *2* or *3*. Contacts with teachers and students seem to bear out the point that in ordinary life situations, generalizations are not usually applied through a formula or equation. Observations of the manner in which students apply generalizations also indicate that it is possible to have the ability to apply them as indicated in *2* and yet not be able to make numerical calculations as in *1*. For example, a student in a physics class at Ohio State University was consistently receiving low marks because of his inability to work problems by the formula method. The instructor said, however, that this student often raised critical questions and appeared to have a better understanding of physical principles than was indicated by his inability to make numerical calculations which involved the use of a formula.

[1] Smith, Tyler and Heil, "Evaluation of Student Achievement in the Physical Sciences," Am. Phys. Teacher 5, 102 (1937).

When this student was given the opportunity to apply the generalizations in the manner indicated by *2* he ranked highest in the class. The following question is typical of those asked in the test given to the class of which this student was a member:

> A 75-w, 100-cp lamp was located 4 ft. above a student's desk. The lamp burned out and was replaced by one of 25-w, 24-cp. The new lamp was lowered to a position 1 ft. above the desk. Neglecting scattered or reflected light, find the change, if any, in the illumination on the desk. *Give your reasons.*

This student's answer to the question was the following:

> There will be four times as much light since the candlepower has been reduced four times and the intensity increased sixteen times by moving the source four times as close; thus, the net increase will be four times. This is because the intensity is inversely proportional to the square of the distance.

Certainly it should not be inferred that the application of generalizations through the more exact method of substitution in a formula is of no value to those students who are planning to enter some phase of a science and who will face a great many problems that require exact numerical solutions. On the other hand, there are many other students who will seldom, if ever, be confronted with problems in which an exact numerical solution is required. It is important, therefore, that the purposes of students be taken into account in deciding those outcomes which are desired.

The Meaning of the Objective

In general, the instructors of the unified course in physics and astronomy desired to have their students apply laws and principles in a manner indicated by class *2*. These instructors felt that a student who was successfully applying generalizations would make a correct prediction or explanation in a given situation and give as his reasons the physical laws and principles which helped him make the prediction.

In order to obtain evidence concerning the achievement of students in applying generalizations to explain or predict phenomena, it was necessary, of course, to have the students write out their predictions together with their reasons. The analysis of these papers showed that some students are able to make good explanations or predictions and to support them with statements of valid physical principles. Other students, mainly those who experience difficulty in making an adequate explanation or prediction, are found to use various types of incorrect or unacceptable reasoning in their answers. When these unacceptable reasons were analyzed, many of them were found to fall into the following categories:

(a) Reasons in which the conditions of the problem are simply restated, or in which the conclusion is restated; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force must be four times as large because of the increase in speed.

(b) Reasons in which the student uses an incorrect analogy instead of the appropriate principles; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force must be made four times as large just as the force necessary to overcome friction becomes four times as large when the speed of an automobile moving in a straight path is doubled.

(c) Reasons that are correct in themselves but that are irrelevant to the explanation of the problem; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force becomes four times as large because the kinetic energy is four times larger.

(d) Reasons that are themselves definitely false; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force must be four times as large because the change per second in velocity is doubled.

(e) Reasons involving a misconception; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force becomes twice as large because the increase per unit time in speed is the same as the increase per unit time in velocity.

(f) Reasons in which reliance is made upon authority of some kind instead of the required principle; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force must be made four times as large because this is an example of Newton's laws.

(g) Reasons that involve ridicule; for example, when the speed of an automobile moving in a circular path is doubled, the centripetal force must be made twice as large because the selection of any other value would indicate a lack of common sense.

Because these unacceptable types of reasoning frequently appear when the students attempt to apply generalizations, the instructors decided that they should also devote a part of their time to developing a clear idea of what is involved in giving adequate reasons when applying principles.

The successful evaluation of students' written

papers was found to present several difficulties. First, even when the instructors have a fairly clear definition of what is expected from students who applied principles satisfactorily, they frequently interpret students' statements differently and hence give them different scores. Second, many of the errors of reasoning are so buried in the students' written responses that it is difficult to identify them in terms of specific classifications such as those indicated above. Third, considerable time is required to make a successful evaluation of students' essays.

There is evidence [1] in support of the contention that the ability of students to remember and know the meaning of laws and principles is not directly related to the ability to apply the generalizations in new examples; that is, students who do well in repeating and explaining a generalization will not always be able to use it in making predictions in new situations. It is for this reason that students in the physical science course at Ohio State University were given the opportunity to *apply* physical principles in *new* situations. Their progress in the development of this ability was thus measured in terms of their achievement when given these opportunities and not in terms simply of their ability to restate the generalizations.

A Short Form Test for Measuring Achievement in Applying Generalizations

To overcome the difficulties encountered in the appraisal of students' papers, it is desirable to develop, if possible, a short form test that will give a reliable index of the students' ability to apply generalizations. The most important criterion to be applied to such a short form is that of its validity; that is, it should give results that are almost identical with those obtained from the essay type papers of students in which they are asked to apply generalizations.

The following example illustrates one type of short form that has been used successfully as a measure of a student's ability to apply generalizations:

An astronomical telescope is focused on a distant object. It is now turned toward an object nearby. In order to bring the telescope into adjustment for the nearby object, it is necessary to

a. Cover all but the central portion of the objective lens..... ( )a
b. Move the eyepiece toward the objective lens ( )b
c. Move the eyepiece away from the objective lens..... ( )c
d. Replace the eyepiece with one of longer focal length..... ( )d

From the following statements select and check those reasons which you believe support your conclusion:

e. A larger amount of light is received into a telescope from a nearby object than from one of the same size located at a greater distance away..... ( )e
f. Most telescope manufacturers provide an adjustment on the eyepiece of an astronomical telescope..... ( )f
g. The real image of an object produced by a converging lens moves away from the lens as the object is brought nearer to the lens..... ( )g
h. The real image of an object produced by a converging lens moves toward the lens as the object is brought nearer to the lens..... ( )h
i. Spherical aberration in a lens results mainly from the light that passes through the outer portions of the lens..... ( )i
j. In order to focus the telescope it is necessary to move the eyepiece away from the objective lens just as a person must move away from an object that is located too close to the eye for distinct vision..... ( )j
k. The eyepiece must be moved away from the objective lens because the object has been moved closer to the telescope..... ( )k
l. The only problem is that of obtaining a new focus..... ( )l
m. Covering all but the central portion of the objective lens reduces any spherical aberration present and also reduces the brightness of the image..... ( )m
n. If an astronomical telescope is in good adjustment, the image produced by the objective lens is located at the focus of the eyepiece.. ( )n
o. The objective lens of an astronomical telescope is of the converging type..... ( )o

To determine the possibility of the use of this short form as an index of the student's ability to apply principles, a test was constructed consisting of five situations of the kind illustrated above. This test was given during the second half of a one-hour examination in which the first part was devoted to having the students write out their predictions and reasons for the same five situations, described to them as in the following example:

An astronomical telescope is focused on a distant object. What must be done in order to bring the tele-

TABLE I. *Application of principles.*

Name: Brown, J. A.	DATES OF TESTS		
RESPONSES	11-15-36	12-16-36	1-28-37
Incorrect prediction	xxx	xx	xxx
Correct prediction	xxx	xxx	xxxx
Correct reason	xxxxx	xxxxxx	xxxxxxxxx
Misconception	xx		x
Analogy	xx		
Ridicule	x		
Authority	x		
Repetition	x	x	
Irrelevant	xxxxx	xxx	x
False			

Remarks. Mr. Brown apparently is familar with the statements of the generalizations for he did not select false statements of them in any of the tests. The fact that he made correct predictions in only about half of the situations indicates that he has difficulty in applying these principles in order to make predictions at the beginning of the term. That he tends to use incorrect reasoning is evidenced by the fact that he selected nine unacceptable reasons. In this direction, his greatest error was the use of irrelevant facts or generalizations. After two tests had been given and the results discussed, he did not employ unacceptable reasons in the third test.

scope into adjustment when it is turned toward a nearby object? *Give your reasons.*

Several instructors then graded the written papers and the scores were correlated with the grades made by the students on the short forms. Such correlations ranged from 0.75 to 0.85. The correlations between individual instructors' independent marks on the written papers varied from 0.85 to 0.94. These results seem to indicate that the short form given above provides a satisfactory index of the student's ability to apply generalizations.

In addition to the numerical index (of the success with which the students apply principles) given by the short form, other evidence can be inferred from it. This type of test may contain statements of unacceptable reasoning in line with the patterns that have been found previously in students' essay papers. For example, in the situation given above, statement *h* in the reason is false, *f* illustrates the reliance upon authority without giving the necessary principles, *e* is a true but irrelevant statement, *j* involves unacceptable reasoning by analogy, *k* represents a reason that is merely a repetition of the conditions of the problem, and *l* represents a form of ridicule which is devoid of the necessary generalizations. The student who selects such unacceptable reasons to support his predictions obviously needs guidance in order that he may more clearly understand what is involved in applying generalizations.

The responses which students make on these short forms may be conveniently tabulated by the instructor on a summary sheet as in Table I.

The scores made by students on these tests in applying generalizations in new situations are not directly related to the scores that the same students make when they are asked simply to recall the physical facts and generalizations. Fig. 1 illustrates how these scores are related in terms of the ranking of a group of 40 students. The coefficient of correlation of the scores of 70 students between the recall of facts and generalizations and the application of the generalizations in new situations was 60. These data seem to indicate that if teachers are interested in finding whether their students are able to apply laws and

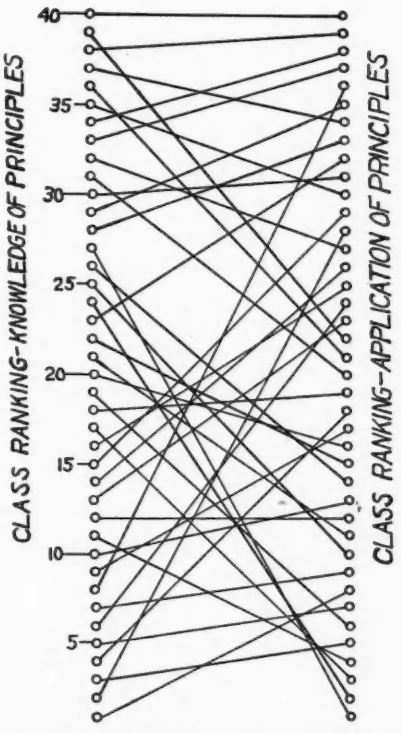

FIG. 1. A comparison of the achievements of 40 students: (left) knowledge of principles; (right) application of principles. The interconnecting lines show the ranking of individual students; for example, the student who ranked 39th in the knowledge of principles placed 22nd in the application of principles in new situations.

principles in new situations, their students must be given the opportunity to apply those generalizations in new situations. The evidence of their accomplishment thus collected must then be appraised in terms of the criterions established by the teacher.

SUMMARY

(a) The application of physical laws and principles may be classified into three types:

(1) direct substitution into a formula;

(2) use of the generalization to predict a result qualitatively when one or more of the functionally related factors are varied;

(3) use of the principle to describe phenomena in a qualitative manner where no prediction is made.

(b) In giving reasons for predictions which they make, students often give a variety of unacceptable answers which include repetition of conclusion or conditions, authority, ridicule, analogy, irrelevant principles, and misconceptions.

(c) A short form test may be substituted for the essay type test as a means of determining the ability of students to apply generalizations. Opportunities may be given in the short form for the student to accept incorrect reasoning. The analysis of the responses on the short form may be used for the purpose of diagnosing student difficulties and as a source of specific information to be passed on to other instructors.

(d) Scores on information tests cannot be used as an index of student ability to apply generalizations in new situations.

A Simplified Picture of the Mechanism of Gyroscopic Precession

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IN presenting the description of diamagnetic action to a class of sophomores, the precession of the electronic orbit about the magnetic field axis as a result of gyroscopic action must be invoked. Discussion with students frequently reveals that many of them have not grasped the mechanism of gyroscopic action. While they admit that if one defines the vector moment of momentum in the conventional fashion, the direction of precession of the gyroscope about an axis mutually perpendicular to the vector and to the axis of the applied torque follows logically, they complain that this is not an adequate "explanation." This complaint is entirely justifiable, for the assignment of the vector is a pure artifact, which happens to work. It is not possible to visualize it mechanically. In the case of an electrified particle moving in a circular orbit with constant speed, however, it is not difficult to show how it is that the resultant precessional velocity is about an axis at right angles to the direction of the applied torque. The presentation leads at once to an evaluation of the angular velocity of precession and its relation to the applied torque. With little difficulty the picture can be carried over in a generalized fashion to the case of the solid mechanical gyroscope. Since this picture leads to a mechanical "understanding" of precession, and since I have been unable to find it presented in any text, it is believed to be worth publication.

For simplicity, consider a charged particle m moving with constant speed $v=r\omega$ about a circular orbit $ADBC$ of radius r (Fig. 1). This orbit lies with its plane parallel to a uniform magnetic field H which has the direction BA. Let m have a charge of $-e$ e. m. u. There will then be a force Hev upward on the particle when it is at A and a downward force Hev when it is at B. At any point m along this orbit, making an angle θ with AB, the force will be $Hev\cos\theta$, upward in the region CAD and downward in the region DBC. The force is zero at the points D and C.

It is at once clear that at the points D and C the particle will have an upward and downward velocity, respectively, due to the acceleration of the particle upward by the force in CAD, and downward by the force in DBC. Due to the uniform character of the orbital motion, the force

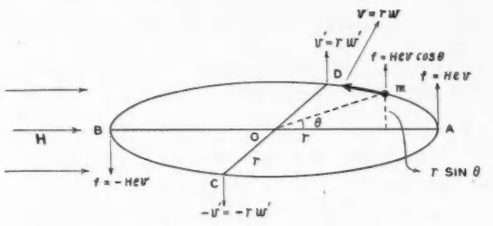

FIG. 1. The mechanism of gyroscopic precession.

upward in quadrant CA and downward in quadrant DB will just decelerate the particle so that its velocity $-v'$ at C and v' at D are reduced to zero at A and B, respectively. Thus *while the force on the particle and hence the torque is a maximum at A and B, the vertical velocity is zero.* On the contrary, *at C and D, where the force on the particle is zero, the vertical velocity due to acceleration in the quadrants AD and BC is a maximum.* Hence with a torque tending to cause this orbit to rotate about AB, the inertia and the motion of the particle along AD and BC result in *the maximum velocity v' being manifested about the axis AB.* At each point of the orbit given by θ there is likewise a component of velocity either up or down, *about the axis AB*, except at A and B, *such that the orbit rotates or, better, precesses about AB.* Hence precession about the axis AB when the torque acts about an axis CD at right angles is merely the result of the inertia of m and the uniform circular motion which causes a delay of 90° between maximum force application and maximum velocity acquired.

Since $v' = r\omega'$ is the result of the angular acceleration α_{AB} about axis AB from the point A to the point D, we can at once evaluate ω' by summing up the various values of $\alpha_{AB}dt$ over time intervals dt from A to D. Now α_{AB} is merely the component of the instantaneous torque about AB divided by the moment of inertia I. This is, at any point, $fr \sin\theta/I$ or $Hev \cos\theta \cdot r \sin\theta/I$. Since $dt = d\theta/\omega$, where ω is the angular speed in the orbit,

$$\omega' = Hevr/I\omega \int_0^{\pi/2} \sin\theta \cos\theta \, d\theta.$$

Hence $I\omega\omega' = Hevr/2$.

Now if we have a coil of wire bent into a plane loop of area A, with a current i in it, perpendicular to a uniform magnetic field H, the well-known galvanometer formula states that the coil experiences a torque G given by $G = iAH$. The charged particle in the orbit constitutes a current $-i = -e\omega/2\pi$ in a counter-clockwise sense. The area of the circuit $A = \pi r^2$. Hence $G = -(e\omega/2\pi)\pi r^2 H = Hevr/2$. It is thus seen that for this very simple case of gyroscopic orbital precession we have $G = I\omega\omega'$ in conformity with the classical deduction. We have, however, not used the artificial vector concept but, instead, have deduced ω' in terms of a readily visualized mechanical process. A similar type of analysis for the more complex mechanical gyroscope can be made. There, however, the offset of the axes complicates the analysis.

European Tour for Physicists

AS announced by Professor R. M. Sutton at the annual meeting in Indianapolis, the plans for the tour of European laboratories are rapidly taking shape. Two options are presented: a six-weeks' tour of England, Germany, France, Holland, Belgium and Switzerland at a cost of $595; a seven-weeks' tour accompanying the first as far as Munich and then turning south to Italy, at an additional cost of $120.

The group will sail from New York on the *Bremen*, July 3, 1938. After a short trip to Salisbury, Stonehenge, Stratford-on-Avon, Warwick, Kenilworth, and Oxford, there will be five days in and around London, with trips to Cambridge, Teddington (National Physical Laboratory), Greenwich (Royal Observatory), etc. Several days will be spent in Holland and Belgium with emphasis upon Leyden and Eindhoven (Phillips Lamp Works) and visits to The Hague, Amsterdam, Marken, and Brussels. Five days are scheduled for Paris, with its reopened International Exposition. A short stop will be made in Zurich en route to Munich, where the group will spend several days. On July 29 those who have elected to turn southward will go to Innsbruck, Austria, while the others will turn northward to Nuremberg. The southern tour will include Milan, Venice, Florence (3 days), Pisa, Rome (3 days), and Naples (Pompeii). This group will return on the *Rex* by way of Genoa, Villefranche, and Gibraltar, arriving in New York on August 17. The other group will reach New York on August 11 after stops at Jena (Zeiss Works) and Berlin (5 days).

Advance contacts are now being made with physicists at the laboratories along the routes, so that the group will be assured of hospitable receptions and profitable visits.

Those desiring to enroll may do so by making a deposit of $10 (refundable in case of withdrawal before June 4) with the tour manager, Mr. William M. Barber, Babson Park, Mass. Additional information may be obtained from Mr. Barber or from the tour leader, Professor R. M. Sutton, Haverford College, Haverford, Pa.

The Teaching of Ohm's Law

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A WELL-KNOWN elementary textbook of college physics states that Ohm's law is one of the most important laws in physics. Whether this be true or not, it is certainly important enough to have the same meaning in all texts. Although the law was enunciated 110 years ago, we find even in modern texts several distinctly different statements as to its meaning and use. All the advanced texts consulted by the author are self-consistent, although the statement of the law in one text might be different from that in another. This is also true of some elementary texts of college grade, but unfortunately certain other elementary texts are not even self-consistent; the law is stated in one way, and then so applied that, if one is to arrive at the correct solution of a problem, general or specific, it is necessary to use some other generalization as Ohm's law. A physicist familiar with electric circuits, having seen different statements of the law in different texts, is able to change his mind as to its meaning whenever the author does, and thus there is an apparent consistency. The elementary student is quite incapable of doing this, however. Having seen Ohm's law stated in one way, he expects the author to stick to this statement. When another generalization is substituted without any explanation or discussion, he is confused, and perhaps rightly. It is not asserted that these textbooks are necessarily incorrect, but rather that the authors expect the beginner to know more than is possible for him to know. At least five different statements of Ohm's law are found in textbooks. If all authors used precisely the same statement of the law, and held rigidly to it, this would be of great benefit to all students of electricity.

In order to illustrate clearly the points that are to be made, we shall refer to the circuit equations for the stationary electromagnetic field as developed by Planck.[1] He refers to the case of linear conductors, assuming all the cross sections of the conducting systems to be infinitely small; a cross section is therefore an equipotential surface, the potential of which is taken as φ. This is substantially the condition that exists in nearly all practical, continuous current circuits, with the cross section areas of the conductors uniform and finite. It will be assumed that the resistance of any conductor may be computed from the equation $R=\rho L/A$. Let ΣE denote the sum of the contact potentials, or electromotive forces, that lie between the cross sections *1* and n in a circuit; Σw, the sum of the resistances between *1* and n; J, the current; φ_1, the potential of any point of section *1*; and φ_n, the potential of section n. Planck derives the equation [Eq. (250), p. 128]

$$J=(\varphi_1-\varphi_n+\Sigma E)/\Sigma w.$$

By passing about a complete circuit, Planck then permits section n to become coincident with section *1* and, since φ is single-valued, obtains $\varphi_1=\varphi_n$; therefore [Eq. (251), p. 128],

$$J=\Sigma E/\Sigma w.$$

He says:

> This is Ohm's law. It states that the intensity of the current in a closed system of conductors is equal to the quotient of the total electromotive force by the total resistance of the current circuit.

It is to be noted that this particular statement of Ohm's law is quite restricted, and hence not very useful. It is applicable only to a closed path, and therefore may not be applied to a portion of a circuit. Also, in his derivation, Planck contemplated only a simple series circuit; neither of his equations can be applied to a branch circuit containing emf's in several branches. A slight modification, effected by including J under the summation sign, makes both equations more general. When this is done, however, what Planck calls Ohm's law becomes Kirchhoff's second law. These equations are now listed for future reference:

$$\varphi_n-\varphi_1=\Sigma E-\Sigma Jw, \qquad (1)$$

$$J=\Sigma E/\Sigma w, \text{ [closed path]} \qquad (2)$$

[1] *Introduction to Theoretical Physics*, Vol. III (Eng. tr., Macmillan, 1932), Chap. V.

$$\Sigma E = \Sigma Jw. \text{ [closed path]} \quad (3)$$

For a portion of a circuit that contains no emf's, but which carries current, Eq. (1) becomes

$$\varphi_1 - \varphi_n = \Sigma Jw. \quad (4)$$

Excluding minor variations, we find that textbooks can be classified as to their statements of Ohm's law as follows:

(A) The law is stated substantially as: *the current in a simple series circuit is equal to the quotient of the total electromotive force and the total resistance of the current circuit.* This is equivalent to Eq. (2) and must not be applied to a portion of a circuit, if the usual definition of emf obtains.[2]

(B) The law is stated substantially as in (A) with the additional statement that *it may apply to portions of the circuit as well as to the entire circuit.* No explanation is made as to why or how this can be done. Electromotive force is defined in these texts in the usual manner, thus making it impossible to apply Eq. (2) to a portion of the circuit. This is very confusing to a student. Apparently the authors assume that Eqs. (2) and (4) together comprise Ohm's law, the former for the closed path, the latter for a portion of a circuit; but no clear statement to this effect is made.[3]

(C) The law is stated substantially as in (A), with a definite statement that *this is to apply only to a closed path*, and an additional statement, made to cover application to a portion of a circuit, substantially as follows: *the fall of potential, or potential drop, between any two points of a wire or other linear conductor in which a current exists, stands to the current through the conductor in a constant ratio which is called the resistance between the two points.* This is equivalent to the statement that Eqs. (2) and (4), together, comprise Ohm's law, but a careful distinction between the equations is made.[4]

(D) The law is stated substantially as follows: *the potential drop between two points of a wire or other linear conductor is equal to the product of the resistance between these points and the current.* This is equivalent to the statement that Eq. (4) expresses the entire content of Ohm's law.[5]

(E) The law is stated substantially as follows: *the emf acting between the extremities of any part of a circuit is equal to the product of the current and the resistance of that part of the circuit.* It seems difficult to gain a clear understanding of the meaning of this sentence. It might mean that the potential drop across a resistance is defined as an emf, or it might mean that a portion of the emf is "consumed" in the resistance. In any case it does provide a concept of emf that is not in agreement with a large majority of textbooks.[6]

Historically, it appears that Ohm[7] discovered, among other things, the generalizations stated under (A) and (D). Although (A) is so restricted as not to be very useful, when generalized slightly so as to take care of closed paths in any kind of a branch circuit, it becomes Kirchhoff's second law, and thus is highly useful. It would seem, therefore, if Ohm's law is to express a single generalization, rather than two or more, Eq. (4) is the most serviceable.

Of course it is entirely possible to omit all reference to Ohm's law in connection with

[2] An example is reference 1, an advanced text.

[3] Examples are: S. L. Brown, *Electricity and Magnetism* (Holt, 1937); Duff, etc. *Physics* (Blakiston, 1926); Hausmann and Slack, *Physics* (Van Nostrand, 1935); N. H. Black, *Introductory Course in College Physics* (Macmillan, 1935); W. B. Anderson, *Physics for Technical Students* (McGraw-Hill, 1925); C. A. Culver, *A Textbook of Physics* (Macmillan, 1936). All are elementary texts.

[4] Among the advanced and intermediate texts using this scheme are: L. Page, *Introduction to Theoretical Physics* (Van Nostrand, 1928); A. W. Hirst, *Electricity and Magnetism* (Prentice-Hall, 1937); L. B. Loeb, *Fundamentals of Electricity and Magnetism* (Wiley, 1931); W. C. Dampier-Whetham, *The Theory of Experimental Electricity* (Cambridge Univ. Press, 1912). The elementary texts include Millikan-Gale-Edwards, *A First Course in Physics for Colleges* (Ginn, 1928); W. Robinson, *The Elements of Electricity* (Wiley, 1922); N. C. Page, *Lessons and Problems in Electricity* (Macmillan, 1936).

[5] Examples among the advanced and intermediate texts are: J. H. Jeans, *The Mathematical Theory of Electricity and Magnetism* (Cambridge Univ. Press, 1915); T. Wulf, *Modern Physics* (Eng. tr., Methuen, 1930); S. G. Starling, *Electricity and Magnetism* (Longmans, Green, 1929); H. E. Hadley, *Magnetism and Electricity for Students* (Macmillan, 1906); W. V. Houston, *Principles of Mathematical Physics* (McGraw-Hill, 1934); G. H. Livens, *The Theory of Electricity* (Cambridge Univ. Press, 1918). The elementary books include: A. A. Knowlton, *Physics for College Students* (McGraw-Hill, 1928); Randall, Williams and Colby, *General College Physics* (Harper, 1937); Mendenhall, Eve and Keys, *College Physics* (Heath, 1935).

[6] Examples among advanced and intermediate texts, are: J. C. Maxwell, *Electricity and Magnetism* (Clarendon Press, Oxford, 1873); Page and Adams, *Principles of Electricity* (Van Nostrand, 1931); A. Haas, *Introduction to Theoretical Physics* (Constable, 1924). The elementary texts include A. W. Duff, *College Physics* (Longmans, Green, 1932); L. B. Spinney, *A Textbook of Physics* (Macmillan, 1937); Weld and Palmer, *Textbook of Modern Physics* (Blakiston, 1930).

[7] G. S. Ohm, *Die Galvanische Kette Mathematisch Bearbeitet* (1827).

circuit equations, and to use in its stead the much more general, useful and understandable Eq. (1). Written in notation more suitable for elementary texts, it becomes

$$\mathcal{E}_{ab}=\Sigma e-\Sigma RI, \qquad (1')$$

where $\mathcal{E}_{ab}$ denotes the potential difference between any two points a and b in any kind of a branch circuit (with proper restrictions as to temperature, linear conductors, etc.); Σe, the total emf acting between the points a and b by any path; and ΣRI, the sum of the potential drops by the same path. Applied to a closed path in a complex circuit, $\mathcal{E}_{ab}$ becomes $\mathcal{E}_{aa}=0=\Sigma e-\Sigma RI$, which is Kirchhoff's second law, or in special cases, Eq. (2). Applied to a portion of a circuit containing no emf's, it becomes Eq. (4). It thus is possible to solve all types of circuit problems with the use of Kirchhoff's first law and Eq. (1'), which thus replace the various statements of Ohm's law and Kirchhoff's first and second laws. The range of validity of Eq. (1') is the same as that for Ohm's law. The conditions for which Ohm's law is valid are quite frequently given erroneously in textbooks, but this point has been treated adequately in a letter to this journal.[8]

If Ohm's law must be used, it should be possible for all authors to agree as to its exact content and meaning; but, above all, elementary textbooks should be self-consistent.

[8] E. R. Laird, Am. Phys. Teacher **2**, 177 (1934).

An Elementary Laboratory Experiment on Moment of Inertia

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THERE has been developed in this laboratory apparatus for the determination of the moment of inertia of a disk which combines accuracy with simplicity and ruggedness. The usual method is to allow a weight to fall, thus producing rotation of the disk whose moment of inertia is desired, and then to obtain data for the calculation of the angular acceleration produced. These data are usually obtained with some sort of sparking device or electrically driven tuning fork with attached stylus. Although this manipulation can yield data leading to accurate results, it has been our experience with similar devices used in connection with "free fall apparatus" that students have trouble in getting the proper traces and in making accurate measurements from them. In addition, these accessories increase the cost considerably.

Figure 1 shows the assembled apparatus. The large disk is the one whose moment of inertia is to be determined. It is made of steel 14 cm in diameter and 3.6 cm thick. Its center is drilled to permit an axle 0.8 cm in diameter to be inserted. The axle itself rests on self-aligning ball bearings (SKF, 1200A) on either end; the bearings are held in place by the vertical supports, which are made of hexagonal brass 2.2 cm in diameter. A pointer mounted on a friction sleeve fits into a hole concentric with the axle in the vertical support. The weight which is seen resting

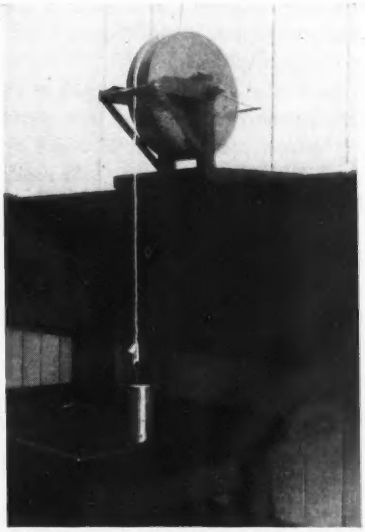

Fig. 1. Photograph of apparatus.

on the stool is fastened with a string to a small steel bar. This bar rests against two short pins projecting from the rim of the disk. When allowed to fall the weight imparts some of its energy to the disk until the small steel bar is picked off the pins by the framework built out in front. In performing the experiment the pointer is first set diametrically opposite the point on the framework where the steel bar is picked off. Thus the weight falls through a distance equal to half the circumference of the disk. If we let m be the mass of the falling weight, M the mass of the disk, M' the mass of the axle, I the moment of inertia of the disk and axle, R the radius of the disk, r the radius of the axle, v the speed of the falling weight, and ω the angular speed of the disk at the end of the half-rotation, the energy equation is

$$mg\pi R=\tfrac{1}{2}mv^2+\tfrac{1}{2}I\omega^2. \quad (1)$$

From this equation I can be calculated if ω is known, and can then be compared with the value obtained from the equation,

$$I=\tfrac{1}{2}M(R^2+r^2)+\tfrac{1}{2}M'r^2. \quad (2)$$

The terms involving r might well be neglected; they are included for instructive value only.

Our method differs from the one usually employed in that it depends upon the determination of ω instead of angular acceleration. The procedure is as follows. The disk is turned until the small steel bar is at the pointer. The disk is then released and the time to make the first 20 rotations from the point at which the falling weight is removed is determined. This procedure is repeated to obtain the time for the first 40, 60, 80 and 100 rotations. The number of rotations, expressed in radians, divided by the time interval gives the average angular speed $\bar{\omega}$. If the frictional resistance is constant, the resulting angular acceleration $-\alpha$ will be constant, and we may write $\bar{\omega}=\omega-\frac{1}{2}\alpha t$. Then the graph of $\bar{\omega}$ *versus* t should be a straight line, the intercept on the $\bar{\omega}$-axis giving the value of the angular speed sought. As an additional exercise the value of α may be determined from the slope of the line. The apparatus is easily disassembled for weighing and measuring by merely pulling out the axle.

TABLE I. *Typical data obtained by a student.*

No. of rot.....	20	40	60	80	100
Time (sec.).....	12.5	26.2	41.7	59.1	81.2
$\bar{\omega}$ (rad./sec.).....	10.1	9.59	9.04	8.50	7.73

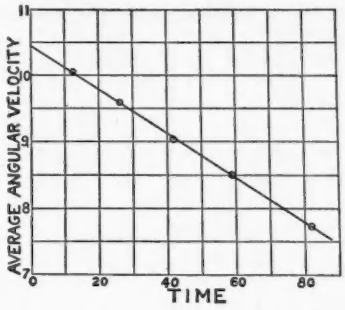

FIG. 2. Graph for determining the initial value of ω.

In Table I the time is an average of five trials. Plotting a graph (Fig. 2) we find the initial angular speed to be 10.45 rad./sec. For the apparatus used, M is 4100 g, M' is 45 g, m is 292 g, R is 7.0 cm, and r is 0.40 cm. Substituting these values in Eqs. (1) and (2) we find I to be 101,000 and 100,800 g cm^2, respectively. Although only the most careful students obtain results in such close agreement, the average difference between the two results for some 80 students this term has been about 2 percent.

We give below some observations which we have made during the many years the experiment has been in use. It has been found that if the falling weight is too heavy the graph of Fig. 2 is not a straight line. It is advisable not to use data involving the last 10 or 20 rotations. As the two short pins are somewhat hard to see when the wheel is rotating, a chalk mark is usually made on the side of the disk by the pins. For best results it has been necessary to clean the bearings once a year with kerosene and lubricate with a very light, good oil. Until recently we used stopwatches to obtain the time interval, but now use an electrical timer such as has been described by Harrington.[1]

[1] Am. Phys. Teacher **2**, 170 (1934).

Moments of Inertia for First-Year Physics Students

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IT seems to be the general practice in many colleges to have students take the first course in physics before they have had a course in mathematical analysis. At least, most physics textbooks are written for students who have not yet learned to differentiate or to integrate. As a result, many such books embark upon a discussion of moments of inertia, for example, and then suddenly cut the discussion short with a table and the statement that to compute moments of inertia requires the methods of the calculus.[1]

Such a statement is not too satisfying to the keener intellects of a class. In addition, the statement is not entirely true. It so happens that the moments of inertia of many figures can be computed by the methods of intermediate (third-year secondary school) algebra. Amongst these are the filament, the rectangle, the disk, the cone, the frustum, the sphere and many other figures of revolution. Some instructors might want to use these methods in the classroom, and many more might like to have them accessible for the bright student who asks questions.

The methods to be described involve the use of the following theorems:

$$\Sigma n = 1+2+\cdots+n = (n^2+n)/2,$$
$$\Sigma n^2 = 1+4+\cdots+n^2 = (2n^3+3n^2+n)/6,$$
$$\Sigma n^3 = 1+8+\cdots+n^3 = (n^4+2n^3+n^2)/4,$$
$$\Sigma n^4 = 1+16+\cdots+n^4 = (6n^5+15n^4+10n^3-n)/30.$$

The first of these is the arithmetic progression, with which the student is already familiar. The proof of the others will be illustrated by that for Σn^2. Let

$$\Sigma n^2 = an^3+bn^2+cn+d,$$

where the coefficients a, b, c, and d can be determined by substituting small numbers for n. Thus, when

$$\begin{aligned} n=1,&\quad a+b+c+d=1,\\ n=2,&\quad 8a+4b+2c+d=5,\\ n=3,&\quad 27a+9b+3c+d=14,\\ n=4,&\quad 64a+16b+4c+d=30. \end{aligned}$$

Here we have four linear simultaneous equations in four unknowns. The solutions are: $a=1/3$; $b=1/2$; $c=1/6$; $d=0$. Therefore

$$\Sigma n^2 = n^3/3+n^2/2+n/6 = (2n^3+3n^2+n)/6.$$

Of course, we could have taken as many terms as we had wished in the expression for Σn^2, but all the coefficients except a, b, and c would have vanished. Finally, we must have

$$\Sigma n^2 - \Sigma(n-1)^2 = n^2,$$

which condition the formula obeys. It is therefore proved.

The proofs of the other formulas are exactly parallel. It is not necessary to repeat them here.

Next, we must observe that when n is a very large number, these formulas lead to the following results:

$$\lim_{n\to\infty}\frac{\Sigma n}{n^2}=\frac{1}{2},\quad \lim_{n\to\infty}\frac{\Sigma n^3}{n^4}=\frac{1}{4},$$
$$\lim_{n\to\infty}\frac{\Sigma n^2}{n^3}=\frac{1}{3},\quad \lim_{n\to\infty}\frac{\Sigma n^4}{n^5}=\frac{1}{5}.$$

We shall now find the expression for the moment of inertia of a filament about an axis through one end.[2] Let the length of the filament be A and let its mass be M. Divide the length into n equal divisions, where n is a very large number. The mass of each division will be M/n and the length, A/n. The distance of the kth division from the axis about which the moment is being computed will be kA/n. The moment of inertia of this kth division about this axis will be $(M/n)(kA/n)^2$ and the moment of inertia of the

[1] For an exception to this statement, see E. Edser, *General Physics for Students* (Macmillan, 1922), pp. 47–57. The algebraic methods described by Edser are quite different from those described in this article.

[2] The substance of this paragraph is given in Kimball, *College Text in Physics* (Holt, ed. 4, 1929), p. 102, but without proof of the summation theorem.

entire filament will be

$$I=(M/n)(A/n)^2+(M/n)(2A/n)^2 +\cdots+(M/n)(nA/n)^2$$
$$=MA^2\Sigma n^2/n^3=MA^2/3.$$

To find the moment of inertia about an axis through the center of mass, we can consider the filament to consist of two similar sections on either side, and to have mass $m=2M$ and length $a=2A$. Then the moment of inertia about the axis in question is

$$I_0=2MA^2/3=ma^2/12.$$

To find the moment of inertia about an axis through any other point of the filament distant c from the center of mass, let the mass between the center of mass and the axis be N, and let $m=2M$ and $a=2A$ as before. Then

$$I=\tfrac{1}{2}[(M-N)(A-c)^2+(M+N)(A+c)^2]$$
$$=\tfrac{1}{2}[2MA^2+2Mc^2+4NAc]$$
$$=\tfrac{1}{2}[2MA^2+6Mc^2]=I_0+mc^2,$$

since $M/N=A/c$ and therefore $NA=Mc$.

The general formula for parallel axes, $I=I_0+Mc^2$, can be presented quite simply to the elementary student as a corollary of the laboratory force-table experiment on the equilibrium of a particle.[3]

In this experiment, the student learns that when the sum of several vectors is zero, the sum of the components along any given direction vanishes. Now, the center of mass is the point for which $\Sigma m\mathbf{r}=0$, where $\mathbf{r}$ is the vector distance to each mass m composing the body. Draw a straight line through this center of mass, and let $m\mathbf{R}$ be the component of $m\mathbf{r}$ perpendicular to this line. Then, since the sum of the components of $m\mathbf{r}$ along this line vanishes, the sum of the remaining components, $\Sigma m\mathbf{R}$, must also vanish.
Now let

$$I_0=\Sigma m\mathbf{R}^2=\Sigma mR^2,$$
$$I=\Sigma m(\mathbf{R}+\mathbf{c})^2$$
$$=\Sigma m[R^2+c^2+2Rc\cos(\mathbf{R},\mathbf{c})].$$

But $mR\cos(\mathbf{R},\mathbf{c})$ is the component of $m\mathbf{R}$ along the line c. Therefore, since $\Sigma m\mathbf{R}$ is zero, $\Sigma mR\cos(\mathbf{R},c)$ must be zero. Thus, since $\Sigma m=M$, $I=I_0+Mc^2$.

Moment of inertia of a rectangular sheet about the axis perpendicular to its own plane through the center of mass. Let the rectangle be composed of $2n$ long thin filaments, where n is again a very large number. Let the mass of each filament be $m/2n$, and its moment of inertia about its own center of mass be $I_f/2n$. If the length of the rectangle is a, and its width b is $2B$, the moment of inertia of the rectangle will be

$$I_0=2\left[\left[\frac{I_f}{2n}+\frac{m}{2n}\left(\frac{B}{n}\right)^2\right]+\left[\frac{I_f}{2n}+\frac{m}{2n}\left(\frac{2B}{n}\right)^2\right]+\cdots +\left[\frac{I_f}{2n}+\frac{m}{2n}\left(\frac{nB}{n}\right)^2\right]\right]$$
$$=I_f+\frac{mB^2\Sigma n^2}{n^3}=I_f+\frac{mB^2}{3}=I_f+\frac{mb^2}{12}$$
$$=m(a^2+b^2)/12.$$

Moment of inertia of a circular disk about its own axis of rotation. Let the whole disk, of radius a and surface density σ, be composed of a central disk of radius b together with n very thin rings, where n is again very large. We will begin by finding the moment of inertia of that portion of the disk between the circles a and b. If the width of this portion is x, the width of each ring of which it is composed is x/n. The mass of each elementary ring is equal to the product of its radius and $2\pi\sigma x/n$, and its moment of inertia is the product of the cube of its radius and $2\pi\sigma x/n$. Thus, counting from the smallest of these rings, the moment of inertia of the kth one is

$$\frac{2\pi\sigma x}{n}\left(b+\frac{kx}{n}\right)^3=\frac{2\pi\sigma x}{n}\left[b^3+3b^2\frac{kx}{n}+3b\left(\frac{kx}{n}\right)^2+\left(\frac{kx}{n}\right)^3\right],$$

thus giving for the entire annulus

$$I_0=\frac{2\pi\sigma x}{n}\left[nb^3+\frac{3b^2x\Sigma n}{n}+\frac{3bx^2\Sigma n^2}{n^2}+\frac{x^3\Sigma n^3}{n^3}\right]$$
$$=\frac{\pi\sigma}{2}[4b^3x+6b^2x^2+4bx^3+x^4]$$
$$=\frac{\pi\sigma}{2}[(b+x)^4-b^4]=\frac{\pi\sigma}{2}(a^4-b^4)$$
$$=\frac{\pi\sigma}{2}(a^2-b^2)(a^2+b^2)=m\frac{a^2+b^2}{2}.$$

Now let b become negligibly small, so that b^2 or b^4 vanishes Then the moment of inertia of the whole disk becomes

$$I_0=\tfrac{1}{2}\pi\sigma a^4=ma^2/2.$$

Moment of inertia of a solid right circular cone about its axis of rotation. This may now be found by considering it to be constructed of n elementary disks. If the density of the cone is ρ, its altitude h, and the radius of its base a, the thickness of each disk will be h/n, and the radius of the kth disk from the base will be $a(1-k/n)$. The moment of inertia will be

$$\frac{\pi\rho h}{2n}a^4\left(1-\frac{k}{n}\right)^4=\frac{\pi\rho h}{2n}a^4\left[1-4\frac{k}{n}+6\left(\frac{k}{n}\right)^2-4\left(\frac{k}{n}\right)^3+\left(\frac{k}{n}\right)^4\right].$$

Having found the moment of inertia of a cone, we may obtain that for a frustum by substraction. The results for a hollow cone and frustum may be found similarly.

Moment of inertia of a sphere or of an ellipsoid of revolution. This may be found by building it of $2n$ disks, where

[3] This demonstration, or one similar, is given in a number of elementary textbooks; for example, Knowlton (McGraw-Hill, ed. 1, 1928), p. 523 (omitted in ed. 2); Randall, Williams, Colby (Harper, 1937), p. 89.

the moment of inertia of the kth disk from the equatorial plane is

$$\frac{\pi\rho a}{2n}a^4\left[1-\left(\frac{k}{n}\right)^2\right]^2=\frac{\pi\rho a^5}{2n}\left[1-2\left(\frac{k}{n}\right)^2+\left(\frac{k}{n}\right)^4\right];$$

or it may be found by building the figure of $2n$ frustums.

With the moments of inertia for the solid figures thus found, those for hollow ones are easily obtained by subtraction, or also by building them of thin rings. Similar remarks apply to figures of revolution in general.

Any one of the foregoing demonstrations will probably suffice to assure the student that the formulas given in the tables of moments of inertia in the textbook are not merely empirical. Other applications of this method will occur to those who are interested.

A Survey of Surveys

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IN 1935 R. J. Havighurst[1] concluded that the number of survey courses in the natural sciences being offered in American colleges and universities had tripled in the period from 1931 to 1935. Recent advices from publishers' representatives indicate that the popularity of courses of this type has enjoyed a continued growth in which saturation has not yet been attained.

Supporting this trend, and supported by it, in the field of the physical sciences a varied shelf of textbooks has come into being. Yet so unstandardized are the details of survey courses in various institutions, and so difficult do authors find the task of writing smooth copy of uniform quality in three or four major scientific fields that, so far, the present writer has not heard any textbook given full approval by any teacher, and his contacts have included teachers who were also authors in this field. Several new books have appeared in recent months and hence an evaluation of available texts from a single point of view may be found timely.

Sometimes the term "survey course" is applied to a brief course within some one scientific department, but in this discussion we will adhere to the more usual usage, according to which a survey course draws its subject matter from two or more of the customary scientific subdivisions. Typically, a survey course in the physical sciences will attempt to impart something from each of the fields of physics, chemistry, geology and astronomy. It scarcely needs to be said that the intention of a course so diffuse will be to contribute something to the student's general education and not to fit him for a scientific career.

With these vast fields open to the authors' selection it would be strange indeed if different textbooks showed any marked similarity in detailed content. There is no single trail through the varied region of the sciences which alone is suitable to the explorer, particularly when that explorer is bent upon a superficial reconnaissance. A logical sequence in his progress is essential but there are many sequences of scientific high spots that are approximately logical. In the metaphor of one author.

> "Like the maid crossing the brook in the painting, we are choosing our stepping stones carefully, lifting up our skirts to avoid entanglement with extraneous matter, and setting our feet squarely on one rock after another in our quest for a firm footing as we progress through this great ocean of truth."

So we find all authors of books designed for a semester or a year course in the physical sciences assembling materials by a process of selective omission which may result in the rejection of such fundamentals as the laws of motion, the quantum theory, or the periodic table. Since science has not the property of infinite compressibility this situation is inevitable and must be accepted with a degree of tolerance. There are limits, however, and in the opinion of the writer they are reached in such a case as Heil's *The Physical World*, which devotes over 400 of its 534 pages to physics and only 2 pages to geology. The preface of this book advises its use as a

[1] Am. Phys. Teacher **3**, 97 (1935).

textbook in physical science but its field of usefulness lies elsewhere.

The approximate portions devoted to topics assignable respectively to physics, chemistry, astronomy, geology and meteorology in five textbooks in current use in physical science courses are stated as percentages in the square brackets in footnote 2. Of course, textbooks in this field are not frankly subdivided into these conventional categories. The "New Plan" texts used at the University of Chicago in the introductory general course in the physical sciences are separate treatments of the several fields by different authors and are not treated here.

Some of the books listed below have been reviewed in this journal[3] and need not be exhaustively reconsidered. Brownell's *Physical Science* is the oldest book listed but it is not yet in serious need of modernization except in a few sections such as those on atomic physics. The choice of subject matter in this work will strike most teachers as suitable and the exposition, while not entirely free from misstatements, is lucid and generally satisfactory. Written by a specialist in the art of science teaching, the book is well furnished with such aids as review questions, bibliographical references, and descriptions of experimental demonstrations. In spite of the availability of newer texts this brief book should remain upon the eligible list.

Man and the Nature of his Physical Universe, by Jean, Harrah, Herman and Powers, was all but demolished some three years ago in a review in this journal that concluded with the sentence, "Those scientists who are genuinely concerned about some of the present trends in science education should find in this book many things to justify their worst fears." Unquestionably this text is defaced by many amazing misstatements. While this feature may be sufficient to condemn the work in the minds of many teachers it is no more than just to credit the authors with commendable aims,[4] an acceptable choice of subject matter, interesting presentation, and a convenient organization of material into coherent units well designed for the emphasis of a few great generalities. These features make more regrettable the authors' limited acquaintance with some of the branches treated. The preface of the book offers a protest against the distortion of viewpoint which sometimes results from the use of textbooks by subject-matter specialists, but succeeding chapters furnish many indications that the specialist with his customary ideas of rigor may still have his uses in the textbook field.

College Physical Science, by McCorkle and Lewis, is designed for a one-semester course, and marks an achievement in the arts of omission and condensation. Much of the development of the well-balanced list of topics is left to the teacher. Inaccuracies are relatively few.

Bawden's *Man's Physical Universe* is presented as an attempt to improve upon the work of Jean, Harrah, Herman and Powers, and in the opinion of this reviewer the attempt has resulted in success. With 50 percent greater length Bawden has been able to give many topics fuller treatment than they received from the earlier authors and to introduce additional material. The book is organized in ten units each consisting of from three to eleven sections suitable in length for one day's assignment. On such a schedule the book may be covered in a year course meeting three times a week. Each unit is introduced by and devoted to the development of an assertion such as the following:

> The universe is a vast system of parts moving and changing under the influence of a flow of energy.
>
> Man is mastering his material world through an ever-increasing understanding of its nature.

[2] **Physical Science.** Herbert Brownell, professor of the technique of instruction in science, University of Nebraska. *McGraw-Hill*, 1931. [38, 13, 15, 18, 7.]

Man and the Nature of His Physical Universe. Frank Covert Jean, Ezra Clarence Harrah and Fred Louis Herman, Colorado State Teachers College. With the editorial collaboration of Samuel Ralph Powers, Teachers College, Columbia University. *Ginn*, 1934. [40, 2, 26, 18, 9.]

College Physical Science. Paul McCorkle, professor of physics and physical science, and J. Arthur Lewis, professor of chemistry and physical science, State Teachers College, West Chester, Pa. *Blakiston's*, 1934. [39, 16, 16, 17, 12.]

Man's Physical Universe. Arthur Talbot Bawden, College of the Pacific, *Macmillan*, 1937. [25, 19, 12, 23, 5.]

The Universe Surveyed. Harold Richards. *Van Nostrand*, 1937. [33, 20, 22, 15, 5.]

[3] Am. Phys. Teacher **3**, 38, 92 (1935).

[4] "Administrators . . . are insisting that the required general courses in science shall help the student to locate himself in his universe; that they shall help to free him from superstition and prejudice; that they shall teach him to rely upon established truth in ordering his own life and to value the leadership of the specialist; that they shall enable him to appreciate the careful, logical methods employed by the scientist in arriving at trustworthy conclusions; in short, that the generalizations of science shall be presented in such a way as to influence in a significant manner the beliefs, philosophy, and attitudes of the average student."

Nearly all of the 368 figures are good and many are new to textbooks. The useful lists of study questions which terminate the sections contain not only simple review questions but others, well designed to extend the student's thinking. An admirable bibliography listing over 400 relevant books indicates the breadth of the author's interests and of the area from which he has collected his materials.

In the matter of accuracy it is necessary to state that *Man's Physical Universe* contains altogether too many erroneous statements and careless oversights to be lightly forgiven, even in a first edition. A casual first reading produced a list of more than a hundred. The more flagrant mistakes are frequently the less objectionable since they are readily detected, but even so a book that is to be placed in the hands of freshmen should not make statements like the following:

. . . For every reaction there is an equal and opposite reaction [sic].

The reason why the earth travels in an elliptical path is explained by Einstein to be the result of its mass and speed.

. . . up to the present time man has failed in all of his attempts to increase or decrease it [radioactivity], or even start or stop it.

The average height of all the land on the earth's surface is 23,000 feet above sea level.

Thus highest tides occur on the sides next to and opposite the moon.

San Francisco was all but destroyed in 1906, and Santa Barbara and Long Beach met similar fates in 1925 and 1933. [This from a Californian!]

Mount Lassen is the only active volcano in North America.

All soil is produced from rocks by the various processes of erosion.

The angstrom unit is 10^{-12} meter.

Iron exhibits no crystalline structure.

Small molecules move more rapidly than large molecules.

Equal volumes of gases under the same temperature have the same pressure.

The Bohr theory of electronic structure is now generally accepted.

As samples of a large number of equally irritating if less concisely false assertions we have the following quotations which are either partly wrong, very doubtful, or badly stated.

The magneto-optic method of analysis requires months of special training before scientific workers can obtain reliable results with it.

It is essential that every possible error be eliminated in scientific observation.

The meridian is the line passing from north to south through a point overhead. The standard international meridian is a line . . . passing through Greenwich, England.

True solar time is that interval between the passage of the meridian across the center of the sun and its succeeding passage across the center of the sun.

The earth itself would show precession if acted upon by an outside force in such a way as to change its rotational force.

Thus the winter sun is not as hot as the summer sun.

Albert Abraham Michelson predicted in 1910 that there was little left for physicists to do except to extend the significant figures. . . .

It is, however, the common, day-by-day changes in temperature that continually bring the most widespread disintegration of rocks.

The resistance thermometer is measured by the change in the electrical resistance of a coil of wire with changes in temperature.

Thus it is that the direction of the winds over the land areas is largely dominated by the seasons.

Each different kind of liquid has its own heat of vaporization which is defined as the amount of heat (in calories) required to vaporize one gram of water at its boiling point.

As to general style and purpose, Professor Bawden never forgets for a page that he is teaching the young, and his teaching is not of the grudging sort which confines itself narrowly within the limits of a pure science. He expects science to mold lives, and warns his students on an introductory page to accept the risks of the molding process or turn back. Thereupon, as occasions arise in the development of his subject, he sets forth considerations touching upon the goal of humanity, scientific attitudes in personal living, the nature of truth, the social uses of science, and certain relations of science to religion, philosophy, aesthetics, business, contemporary superstitions, national economics, warfare, and political institutions. To the present reviewer, who happens to think with de Kruif that "science for science's sake is balderdash," such excursions seem entirely proper. These large general concerns *are* profoundly involved with scientific matters and, in the interests of the freshman, it seems unwise to leave all the interpretations to teachers who do not understand science. In the matter of interest, also, there is almost no doubt that these topics will engage the attention of the average unscientific student more deeply than will any treatment which he can regard as a sterile discussion of inapplicable facts.

Teaching the uses of science is likely to be more difficult than the teaching of science itself since the former is more speculative, and many teachers, accustomed to the feeling of the solid ground of indubitable fact and mathematical logic beneath their feet, will hesitate to embark upon the dubious waters. Those who do so should know that Bawden really believes in the scientific method in controversial areas and that he is not unreasonably dogmatic in advancing conclusions which this method has yielded in his own thinking.

Finally, there is so much that is good in this faulty book that one can only look forward eagerly to the appearance of a second and completely revised edition.

In *The Universe Surveyed*, Richards has produced a book that is somewhat less consciously didactic but, within its selected field, more lucidly instructive. This author, deliberately resisting encyclopedic temptations, has picked an original trail through physics, chemistry, astronomy, geology and meteorology which can be traversed in 658 pages without undue haste. The principal divisions treat in order the astronomical earth and its cosmic neighbors, matter and energy (including conservation, heat, electricity, atomic structure, and chemical transformations), humanly controlled changes in our physical environment (invention and applied science), and uncontrolled (i.e. geological and meteorological) changes. Ninety-four figures, nearly all from photographs, and 850 true-false review propositions are provided.

The historical thread is woven through the treatment from beginning to end, conferring coherence and humanizing materials sometimes found dry. The author's unquestioned command of words and their uses has made a literary pleasure of the usual drudgery of reading an elementary textbook through at a few sittings. The style at times verges upon the poetic but not to the point of falsification. Hard statements are frequently encompassed by a method of successive approximations which skillfully diffuses the difficulties. Contrasting with this pleasant practice, however, one finds a few very congested doses such as the statement of most of the properties of x-rays in a single paragraph.

Clean-cut misstatements are relatively hard to find. The law of the lever is incorrectly stated; Huygens is called an Englishman and credited with work by Halley; there are a number of dimensional absurdities in the presentation of the pressure caused by molecular motion. Ideas concerning the constitution of atomic nuclei are years behind the copyright date. The author's model of the helium nucleus as an assemblage of four protons and two electrons is presented as an "established fact," but on a later page the electrons are relinquished and the four protons allowed to serve as the nucleus of this element of atomic number two. Exceptionable discussions from sections related to branches other than physics could also be cited.

Geologists as well as the geologically ignorant will approve the clear discussion of diastrophism and vulcanism, though both may well wish for a fuller development of the large number of terms and topics introduced in the discussion of geologic processes, and for a fuller statement of the connections between observations and conclusions relative to the history of the earth. The selection of topics presented in illustration of the modern uses of the sciences of physics and chemistry is admirable, and in their development the author's expository gifts appear at their best.

It is no fundamental criticism of this work to say that in spite of its excellences of conception and execution it will not solve the textbook problem of every physical science course. Teachers with the specialized background of departmental science courses will in some cases unfavorably regard this as a book *about* rather than *in* science. Undoubtedly the total number of scientific concepts presented by Richards is, for better or for worse, far below the corresponding number in Bawden's text. Though not quite a popular book, *The Universe Surveyed* is admirably adapted to the needs of the slightly studious general reader. To such persons and to students and teachers of very cultural courses in physical science it may be confidently recommended.

The Teaching of Geometrical Optics

REPORT OF THE A. A. P. T. COMMITTEE ON THE TEACHING OF GEOMETRICAL OPTICS

THE committee began its work by studying the *Report on the Teaching of Geometrical Optics* published in 1934 by the Physical Society of London. This report deals largely with sign conventions. In this country there is less confusion with regard to sign convention than in England. On the other hand, the committee was of the opinion that several problems not discussed in the English report needed clarification.

The committee has not considered specialized courses in geometrical optics but has limited its attention to the problems arising in the elementary course in general physics and in the more or less standard intermediate courses in light. The latter courses deal primarily with physical optics, so the amount of geometrical optics studied by most undergraduates majoring in physics is unfortunately very limited. It is clear that the presentation of geometrical optics which is most satisfactory for the advanced student is not always best for the beginner.

The committee has agreed on the observations and recommendations that follow.

Geometrical optics in the general physics course

Ray method versus wave front method. We consider the ray method simpler and more natural than the commonly used wave front or curvature method. Some teachers claim that the latter method gives a better physical picture of what takes place than the ray method. We regard this view as illusory; for, a method that neglects interference and diffraction is not truly a wave method. On the other hand, the wave front method has the advantage of not requiring trigonometry.

Many textbooks, especially books using the wave front method, fail to make clear the approximations made in deriving the simple lens equation. The limitation to paraxial rays should be stressed. If the wave front method is used, it should be made clear by the usual wavelet construction how the outer part of the wave changes its direction as it passes through the lens. It should be made plausible to the students, rather than assumed tacitly, that the refracted wave is nearly spherical. In this connection, we wish to warn against the absurd error, found in one widely used intermediate text, of associating the spherical aberration with the approximations involved in the use of the sagitta formula.

In most elementary texts geometrical optics is treated after a discussion of the nature of light and before interference. We consider this order unfortunate and recommend that geometrical optics be treated first. Geometrical optics requires only the simple laws of reflection and refraction, and presupposes no definite conception of the nature of light. Also, it is desirable that the discussion of Newton's and Huygens' ideas on the nature of light be followed immediately by the study of the interference and diffraction effects which are the only optical phenomena that clearly require a wave theory.

The law of refraction. The law of refraction, when first presented, should be stated as an empirical law and should not be derived from Huygens' principle. This derivation may follow later, after the discussion of the nature of light. It is recommended that the law of refraction be written in symmetrical form; for example,

$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

The customary notations i and r for the angles of incidence and refraction should especially be avoided.

Sign convention. Nearly three-fourths of the elementary textbooks published in this country use the convention of considering the object (image) distance positive when the object (image) is real, and negative when the object (image) is virtual. Most of the remaining books use a Cartesian convention, according to which all distances are taken positive in the direction of the incident light. While the latter convention is preferable in advanced work, the "real-virtual convention" is more easily grasped by beginners. We, therefore, recommend this sign convention for the elementary course in general physics. Since only paraxial rays are considered in this course, it is most natural to measure object and

image distances along the axis. We recommend that the simple equation for a thin lens be written in the form

$$\frac{1}{s_1}+\frac{1}{s_2}=(n-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right),$$

where the radii of curvature of the front and back lens surfaces are taken with positive sign when the surfaces are convex, and with negative sign when they are concave.

If this sign convention is adopted in the elementary course, it is natural to use it also in the intermediate courses. Whether this is practical or not, depends upon how much geometrical optics is included in these courses. Students of advanced geometrical optics will have no difficulty in changing to another sign convention.

Thick lens. Some consideration should be given to the thick lens and to combinations of lenses already in the elementary course. Many students have cameras or other optical instruments and are concerned with their action. If the paraxial formula for refraction in a single spherical surface is derived, the student should have no great difficulty in determining the focal points and the position and size of the image formed by a thick lens.

Definitions and terminology. Although it is of value for the student to think of the *index of refraction* of a medium as the ratio between the speed of light in a vacuum and the speed of light in the medium, we consider it unnatural to *define* the index in this way. The definition of the index of refraction should be based on the empirical law of refraction. It should be pointed out that the values for the index found in handbooks are relative to air of standard temperature and pressure. A *ray* of light should not be defined as an infinitely narrow beam of light; for, if one would attempt to produce such a beam, diffraction would cause it to spread out. A ray of light may properly be defined as the axis of a fairly narrow cone of light. If the wave front method is used, a ray may be defined as the normal to a series of progressing wave fronts. These definitions preclude the idea of the ray having a physical reality and prevent students from defining a beam of light as a "bundle of rays." The conception of a ray as the path of energy-transfer is sometimes useful. However, it should be kept in mind that in a crystal the energy-transfer is usually not in the direction of the wave normal.

The term "focal power" is considered unfortunate by most members of the committee. We propose that it be replaced by the term *dioptry*. This concept deserves more attention than it receives in present American textbooks. The *dioptry* of a lens or mirror is most simply defined as the reciprocal of the focal length. For a single refracting interface the dioptry is defined as $(n_2-n_1)/r$, where n_1 and n_2 are the indexes of refraction of the two mediums separated by the interface, and r the radius of curvature of the interface; r is measured positive if the interface is convex toward the medium of index n_1. The custom of measuring dioptry in reciprocal meters, and the standard notation used by opticians, e.g. -3.50 D for a diverging lens of dioptry -3.50 m^{-1}, should be mentioned. However, the unit "one diopter" is considered to be superfluous in the elementary course.

Magnification is defined as the ratio of the linear, lateral dimension of the image to the corresponding dimension of the object. It is considered positive when object and image are both real or both virtual; otherwise, it is taken as negative. For a thin lens or a spherical mirror the magnification is given by $m=s_2/s_1$, where s_1 and s_2 are the object and image distances.

The *magnifying power* of a converging lens used as a magnifier should not be confused with the magnification. We recommend that magnifying power be defined as the ratio of the size of the image formed of a small object on the retina when the lens is held close to the eye, accommodating at infinity, to the size of the image formed on the retina when no lens is used and the object is at the conventional nearest distance d of distinct vision. With this definition, the usual ambiguity is avoided, and the magnifying power is equal to d/f, where f is the focal length of the lens; d may be taken as 25 cm or 10 in. The magnifying power of a telescope is similarly defined as the ratio of the sizes of the image of a very distant object formed on the retina when the telescope is used and when it is not used. The magnifying power in this case is equal to F/f, where F is the focal

length of the objective, and f the focal length of the eyepiece.

The terms *converging* and *diverging* to designate lenses with positive and negative dioptry are considered preferable to the terms "positive" and "negative" used by opticians.

The ideas of "object space" and "image space" present difficulty to the beginning student and are considered unnecessary. Similarly, the term "conjugate" in connection with image and object points should be dropped as unnecessary.

The term "principal focus" is felt to be unfortunate. It is recommended that the image point of an infinitely distant object point on the axis be called the *focal point* of the lens. The two focal points may be distinguished whenever necessary by calling one the *object focal point* and the other the *image focal point* (rather than "focal point of the image space"). The word "focus" is used as a verb or as a noun in such phrases as "the light is focused by means of a lens" and "the light comes to a focus at the screen."

The term "optical center" is unnecessary in the treatment of the thick lens. In the case of a thin lens, it is simpler to speak of the *center* of the lens. The terms "simple microscope" and "compound microscope" are archaic. We recommend instead, *magnifier* and *microscope*.

Only the absolutely necessary technical terms should be used in the elementary course. The following terms are either obsolete or unnecessary: umbra, penumbra, irrational dispersion, secondary spectrum, equivalent thin lens, anomalous dispersion, and dispersive power.

Photometry. Greater emphasis should be placed on photometry. With regard to illumination terminology, we refer to the recommendations of the Illuminating Engineering Society. The Joly photometer should be discussed rather than the Bunsen photometer which is inferior as an instrument and more difficult to explain. The simplest facts regarding the use of stops should be treated in the general course.

Diagrams. The teaching of geometrical optics could be improved if teachers and writers of textbooks would take more pains with diagrams. Characteristic lines should be used for different purposes, for example: (a) full lines with arrows for rays on real paths; dotted lines, on virtual paths; (b) full lines for surfaces, with light cross hatching on the side of the surface on which the medium of greater index lies; (c) dash lines for normal; (d) dot-dash line for axis. When drawings are made on the blackboard, colored chalk is helpful.

The limitation of the method of geometrical optics. It should be emphasized that the applicability of the method of geometrical optics depends upon the large size of lenses, mirrors, prisms, etc. When interference and diffraction have been studied, the limitations of the laws of reflection and refraction should be discussed carefully (if qualitatively). The formula for the resolving power of a lens should be given without proof.

Geometrical optics in the intermediate courses in light

As already mentioned, only a fraction of the time taken up by the intermediate courses on light can be devoted to geometrical optics. The amount of geometrical optics that can be taught will depend primarily upon whether one or more intermediate courses are given. In what follows we list a number of subjects which, we believe, should be included in the intermediate courses, whenever possible, and indicate briefly what we consider the best order and type of treatment.

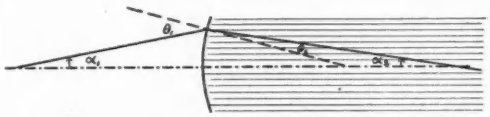

FIG. 1. Refraction in a single spherical interface.

1. *The exact formulas for tracing a ray through a single spherical interface*, namely,

$$(s_1+r)\sin\alpha_1=r\sin\theta_1,$$
$$(s_2-r)\sin\alpha_2=r\sin\theta_2,$$
$$n_1\sin\theta_1=n_2\sin\theta_2,$$
$$\alpha_1+\alpha_2=\theta_1-\theta_2,$$

where s_1 and s_2 are the object and image distances, and α_1 and α_2 the angles which the incident and the refracted rays make with the axis. The angles α_1 and α_2 are measured positive as in Fig. 1, and the radius of curvature r is taken with positive sign if the interface is convex toward the medium with index n_1.

2. When α_1, and hence the other angles, are very small, the angles can be easily eliminated. Thus is obtained

the paraxial equation for refraction in a single spherical interface,

$$\frac{n_1}{s_1}+\frac{n_2}{s_2}=\frac{n_2-n_1}{r}.$$

3. If y_1 and y_2, assumed to be very small, denote the lateral extensions of object and image (taken positive when object and image are real), we have for a single refracting interface,

$$\frac{y_1}{y_2}=\frac{s_1+r}{s_2-r}=\frac{r\sin\theta_1/\sin\alpha_1}{r\sin\theta_2/\sin\alpha_2}=\frac{n_2\sin\alpha_2}{n_1\sin\alpha_1}$$

or

$$n_1y_1\sin\alpha_1=n_2y_2\sin\alpha_2.$$

This is the important *sine relation.*

For paraxial rays, $n_1y_1\alpha_1=n_2y_2\alpha_2$. This is *Lagrange's theorem* which states that the product $ny\alpha$ is invariant for one and, hence, for any number of refractions.

4. *The Gauss theory of lens systems.* Definition of the focal points F_1 and F_2.

Definition of the principal points H_1 and H_2 as the object point and corresponding image point for which the magnification $m=y_2/y_1=-1$.

Definition of object and image focal lengths f_1 and f_2.

Derivation of the relations $n_1/f_1=n_2/f_2$ and

$$m=y_2/y_1=f_1/x_1=x_2/f_2.$$

Newton's equation, $x_1x_2=f_1f_2$, the practical value of which sould be stressed.

If the distance s_1 of the object from the principal object point and the distance s_2 of the image from the principal image point be introduced, the paraxial relations for an arbitrary lens system take the form

$$\frac{f_1}{s_1}+\frac{f_2}{s_2}=1,\quad m=\frac{s_2n_1}{s_1n_2}.$$

In the special case of a lens in air

$$f_1=f_2=f,\quad \frac{1}{s_1}+\frac{1}{s_2}=\frac{1}{f},\quad m=\frac{s_2}{s_1}.$$

Definition of the nodal points N_1 and N_2.

5. *Methods of measuring the focal length of a lens system.* Magnification methods, the nodal slide, and the foco-collimator method.

6. *Dioptry.* Definition of the dioptry D of a lens system as $D\equiv n_1/f_1=n_2/f_2$.

Derivation of the convenient relation $D=n_1\alpha_1/y_2$, where α_1 is the small angle subtended by a very distant object and y_2 the size of its image.

Derivation of the recurrence relation

$$D_i=D_{i-1}+h_i(n_i-n_{i-1}/r_i),$$

where D_i is the dioptry of the part of the lens lying in front of the i'th interface, n_i and n_{i-1} the indices of refraction of the mediums lying behind and in front of the i'th interface, r_i the curvature of this interface (measured positive if the interface is convex toward the medium with index n_{i-1}), and h_i the distance from the axis to the point where a ray entering the lens system parallel to the axis and at unit distance from it cuts through the i'th interface.

Proof of the formula for computing the h_i's, namely,

$$h_{i+1}=h_i-(t_iD_i/n_i),$$

where t_i is the distance along the axis between the i'th and the $i-1$'st interfaces.

The general formula for the dioptry of a lens system,

$$D=\sum_i h_i(n_i-n_{i-1})/r_i.$$

7. *Single thick lens in air.* From the general formulas, one finds at once that

$$D=\frac{1}{f}=(n-1)\left(\frac{1}{r_1}+\frac{1}{r_2}-\frac{t(n-1)}{nr_1r_2}\right),$$

where t is the thickness of the lens. Similarly, formulas for determining the positions of the focal points and the principal points are readily obtained.

8. *Two thin lenses in air,* separated by a distance d. The general formulas give

$$D=\frac{1}{f}=\frac{1}{f_a}+\frac{1}{f_b}-\frac{d}{f_af_b}.$$

9. *Chromatic aberration.* Achromatic and apochromatic lenses.

Chromatic variation of the focal length, as distinguished from the chromatic aberration of the focal point.

10. *Stops,* entrance and exit pupils.

11. *Eyepieces.* Chromatic properties of the Huygens and Ramsden eyepieces.

The use of prisms to produce an erect image.

12. *The fundamental definitions of photometry.* Intensity, illumination, brightness, flux, lumen.

Lambert's cosine laws of intensity and illumination.

The flux radiated by a small plane source into a cone of half-angle θ is given by $F=\pi AB\sin^2\theta$, where A is the area of source and B its brightness.

The lambert and its use.

The brightness of a surface of reflectivity k under an illumination E is given by kE/π.

The illumination at the axial point of a real image is given by $E=k\pi B\sin^2\theta'$, where k is the transmission of the lens, B the brightness of the object, and θ' the slope angle of the emerging ray from the rim of the lens aperture to the axial image-point; hence the conclusion that an object looks equally bright at all distances because the retinal illumination is independent of the object distance.

Proof that the image seen in a telescope cannot appear brighter than the same object seen directly.

The special case of star images formed by a telescope.

The use of a condenser in projection systems.

The speed and f-number of a photographic lens.

Proof that no lens can be made of an aperture greater than f:0.5 on account of the curvature of the principal plane in a well-corrected lens.

13. *The theory of prism spectrographs.* The various types of prisms and prism materials.

The importance of minimum deviation.

The significance of focal lengths of collimator and camera lenses, and the use of a condensing lens.

14. *Elementary description of lens aberrations.* The chromatic aberrations.

Spherical aberration, coma, astigmatism, curvature and distortion.

The dependence of these aberrations upon the stop.

15. *The principal types of lens systems.* Telescope and microscope objectives, which have only small field.

Eyepieces, having wide field and small aperture.

Photographic lenses characterized by wide field and large aperture, ranging from the Hypergon, *f*:30, 75° semi-field, to the *R*-Biotar, *f*:0.85, 5° semi-field.

16. *The eye.* The retina, the lens, the iris, the rods and cones.

Accommodation, myopia and hyperopia; astigmatism.

Color vision.

Resolving power of the eye. It should be pointed out that the separation of the retinal cones and the diffraction of light in the iris lead to about the same value for the resolving power.

The sensitiveness of the eye and its correspondence with quantum theory.

17. *The limitation of geometrical optics.* The resolving power of optical instruments.

Spectral resolving power of prism spectrographs.

The Committee on the Teaching of Geometrical Optics of the American Association of Physics Teachers

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J. B. BRINSMADE,*
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* Died September 13, 1936.

Suggested Four-Year Curriculum Leading to the Degree of Bachelor of Science

BASED ON A REPORT OF THE A.A.P.T. COMMITTEE ON THE TRAINING OF PHYSICISTS FOR INDUSTRY

IN a previous report[1] it was concluded that one definite field for investigation for this committee relates to the content and methods in the curriculum which will best fit men for the positions contemplated, and that in the opinion of the committee the question of curriculum should be discussed independently for the following different classes of students:

1. Those who will take an Arts course with a major in physics;
2. Those who will take a Bachelor of Science course with a higher concentration in physics than is implied in the usual major in physics; this should include those who take courses of study designated as applied or engineering physics;
3. Those who will take a five-year course in general or applied physics leading to the M.S. degree;
4. Those who will take a Ph.D. in physics.

It seemed desirable to begin with class 2 and a sub-committee was therefore appointed to study the formulation of a B.S. in Physics course, with respect to both content and method, that will give the best training to prepare students to enter industry as physicists.

It was stated in the first report[1] that personality, character and innate ability are the primary characteristics which determine a student's success, that this is a factor over which teachers in college physics have little or no control, and therefore, that the committee studies should be based on the assumption that the men to be trained possess these prerequisites. In the discussions of the committee this aspect of the problem comes up repeatedly and will not be suppressed. This unquestionably means that whatever aspects of the training of physicists may be considered, we must still understand and continually remember that the greatest element in the success or failure of a man in his professional career rests on the qualities of personality, character and innate ability which are not greatly affected by any course of study.

There has been general discussion on the question, "What is a physicist?" and it has proved difficult to find a definition satisfactory to everyone. Perhaps for the purposes of the committee it may be best to define a physicist in the terms of the training which he has had. There has been discussion as to the designation to be given to a student who specializes in physics during a four-year college course along a line which can be visualized, although for the present it perhaps cannot be recited explicitly. It is suggested that the term "engineering physicist" has certain undesirable connotations and that a preferable term may be simply *physicist* or *applied physicist.* It is the concensus of opinion of the members of the committee that the expression "engineering physicist" should be avoided.

[1] Am. Phys. Teacher **5**, 91 (1937). The committee will appreciate comments on its reports. These may be addressed to the Chairman, Professor P. I. Wold, Union College, Schenectady, N. Y.

Other articles and notes on the training of physicists for industry that have appeared in this journal are: J. A. Crowther (digest), **4**, 149 (1936); H. L. Dodge, **4**, 167 (1936); A. R. Olpin, **5**, 14 (1937); W. P. Davey, **6**, 11 (1938); Anon., **6**, 52 (1938).

It has been agreed in principle that the purpose of a course of study leading to a B.S. degree in physics should be: (1) to impart to students scientific curiosity and enthusiasm for work in physics; and (2) to give him a thorough training in the fundamentals of physical science. It is the strong conviction of the members present at our meetings that the first objective can be achieved only through the personality and enthusiasm of the teachers rather than by any particular subjects taught.

It is further agreed that the course of study to be evolved and proposed by the committee should (1) lay stress on fundamentals; (2) be flexible and adaptable to many institutions and individuals; and (3) outline general fields to be covered rather than give specific course titles.

The sub-committee appointed to set up a four-year curriculum suitable for the training of industrial physicists has submitted a report. After full discussion and minor changes the committee, feeling that the proposed curriculum meets the specifications already given, has approved that curriculum and urges its study by all interested teachers of physics.

Suggested four-year curriculum

This report of the sub-committee deals with a four-year curriculum that can be made available in any college in which those courses usually provided for the training of engineers are available. Because of the many differences in such institutions the proposed curriculum is made flexible. It is intended to be suggestive and stimulative, rather than rigid and restrictive.

The curriculum divides naturally into two periods of two years each. At most institutions relatively the same ground is covered in the first two years, regardless of the sequence and internal arrangements of the individual courses. In order, however, to divide the time available in two years among the different subjects, it is necessary to select some unit. We have chosen *the student's total time devoted to curriculum work in two years*; that is, *classroom hours plus preparation hours*. The time allotted to different subjects is expressed in percentages of this unit.

TABLE I. *Times allotted to different fields during first two years.*

FIELD OF STUDY	DISTRIBUTION OF TIME (PERCENT)	
Physics	20–25	60–65
Mathematics	20–25	
Chemistry	12–16	
English	8–12	10
Science and engineering	10–15	25–30
Social studies	10–20	

THE FIRST TWO YEARS

It is generally agreed that:

1. The following training in science should be completed by the end of the second year: (a) a thorough general physics course, including laboratory; (b) a thorough general chemistry course, including laboratory; (c) a thorough mathematical foundation, including an introduction to differential equations.
2. Courses in English should be required.

The following additional subjects are suggested from which some of each field should be required:

1. *Science and engineering:* (a) drawing; (b) theory of precision of measurements, including advanced physics laboratory; (c) biology or geology; (d) qualitative and quantitative chemistry; (e) applied mechanics—statics; (f) principles of electrical engineering; (g) shop; and (h) metallurgy.
2. *Social studies:* (a) history; (b) economics and accounting; (c) German and (or) French.

The suggested distribution of the student's time for the first two years is given in Table I.

The objectives of the physics courses of the first two years, in order of their importance, are:

1. Understanding of basic principles;
2. Systematic methods of formulating and solving problems;
3. Mathematical formulation of functional relations;
4. Graphical formulation of functional relationships;
5. Operational (experimental) character of definitions;
6. Frequent glimpses of the engineering and industrial value of physics;
7. Dimensional analysis as a check on equations and computations.

In elementary laboratory work, the primary objective is understanding of basic principles; the technic of measurements should be looked upon as a means, not an end. To avoid stifling initiative, self-reliance and interest, instructions as to procedure should not be too detailed. The experiments selected should lead to interesting and significant final results. Nothing contributes more to these ends than the attitudes of the instructors in charge of the work. Enthusiasm for this important fundamental training is quite contagious. So is the lack of it.

TABLE II. *Times allotted to different subjects during last two years.*

FIELD	SUBJECT	DISTRIBUTION OF TIME (PERCENT)	
Physics	*Required*		
	Mechanics	6–10	
	Electricity	8–12	
	Optics	5–8	
	Electronics	4–6	
	Modern physics	6–10	40–60
	Heat (Thermodynamics)	5	
	Optional		
	Thesis	5	
	Acoustics	4–6	
	Applied physics	5	
	Treatment of experimental data	3	
Mathematics	*Required*		
	Mathematics for physicists	5–10	
	Optional		5–15
	Vector analysis	5	
	Differential equations	5	
	Function theory	5	
Chemistry	*Required*		
	Physical chemistry	8–12	
	Optional		10–20
	Organic chemistry	5–10	
	Qualitative or quantitative	5–10	
Engineering	*Required*		
	Electric circuits	5–10	
	Optional		
	Electrical machinery	5–10	15–25
	Applied mechanics	5–10	
	Metallurgy and metallography	5–10	
	Machine design	5	
	Shop	5	
	Communication	5–10	
	Materials of engineering	5	
	Heat engines	5–10	
	Aerodynamics	5–10	
	Electrochemistry	5–10	
	Fluid mechanics	5–10	
	Kinematics	5	
Cultural and social studies			10–25

THE THIRD AND FOURTH YEARS

Table II indicates the subjects that should be required and those that might well be provided as optional in the last two years. A perusal of the table indicates the wide range of subject material available to a student in this type of curriculum. The fact that selections may be postponed until even the fourth year suggests that such a flexibility should have an appeal for scientifically and practically minded youths who are not certain as to their future work. It also suggests the possibility of outlining sample courses in several fields, such as:

Communication	Chemical physics
Acoustics	Fluid mechanics
Optics	Metals
Electronics	Engineering
Geophysics	Graduate work

Technics that may inculcate desired attitudes in our students are suggested in the following:

1. That in all theory courses great emphasis be laid upon the careful formulation and solution of problems—continually putting to work the basic principles and methods that are taught.

2. That laboratory work accompany the physics courses of the third and fourth years wherever feasible, and that in this work the project method and the improvisation of apparatus from time to time be considered essential.

3. That in laboratory projects, library research on methods and adequate reports be required occasionally.

4. That juniors and seniors be encouraged, outside of their regular curriculum work, to assist in research projects underway, to undertake minor investigations of their own choosing, and to construct apparatus.

5. That absolute course requirements be reduced to a minimum so as to allow the student to formulate his own program, under guidance. Much latitude will thus be left for the exceptional student to make special experiments or studies in which he is interested.

6. That development of initiative and self-reliance be fostered, not by preaching but by expectation; that is, by the atmosphere in which laboratory work and research projects are carried out.

The Committee on the Training of Physicists for Industry of the American Association of Physics Teachers

H. A. Barton, C. A. Campbell, H. N. Davis, W. Wilson, R. A. Patterson, *Chairman of Sub-Committee on B.S. Curriculum*, H. L. Dodge, L. A. DuBridge, *Secretary*, R. Von Nardroff, A. W. Hull, F. G. Keyes, A. G. Worthing, G. R. Harrison, P. E. Klopsteg, P. I. Wold, *Chairman*.

Southeastern Section of the American Physical Society

THE annual meeting of the Southeastern Section of the American Physical Society was held on April 1 and 2 at the University of Alabama. The program included contributed papers on physics research and teaching, an invited address by Dr. K. K. Darrow, of Bell Telephone Laboratories, a luncheon, and the annual dinner.

Where Are Superior Physics Students Found?

REPORT OF THE 1936–37 COLLEGE PHYSICS TESTING PROGRAM

FIVE years ago a national examining program was adopted by a representative group of American college physics teachers. This cooperative approach to the problem of analyzing standards of achievement possessed significance for several reasons. Not only did it represent the first concerted effort of college teachers in any field to supplement personal judgment with measures of demonstrable reliability and comparability, but it also afforded a wider perspective on the performance of individual students and entire classes by indicating their relative placement with respect to thousands of other physics students throughout the country.

The continued cooperation of the Committee on Tests of the American Association of Physics Teachers and the Cooperative Test Service has made it possible to develop this initial survey, carried on in 1933–34, into an annual testing program, serving upwards of 225 colleges each year. The fact that so many institutions have consistently used these tests in appraising performance in the major aspects of introductory physics courses perhaps indicates that certain values which could not be obtained by any isolated college have been realized by this common effort. Notwithstanding very real and definitely recognized limitations in the tests used, they have aided many college teachers in measuring the achievement of individuals and in determining the typical level of performance for a given institution.

Examining programs may serve many purposes. In some places the chief interest in testing centers in a determination of the general quality of students enroled in the first course in physics, whereas in other colleges tests are used primarily to distinguish among the various students, affording one basis for sectioning classes, measuring growth in the fundamental elements stressed in introductory physics courses, or awarding final grades. Everywhere, however, teachers are interested in *the superior physics student.* Instructors may assume different views and practices with respect to the handicapped individual, but no one who is interested either in individual students or in the future development of his field can ignore or overlook the possibilities that reside in the very able student. From the ranks of the above-average group must come the recruits for advanced courses in physics and the talent resources that alone can assure constructive research in this rapidly expanding field.

The present report, based on the results of the 1936–37 physics testing program, which was carried on in the 254 colleges listed in Table I, concerns particularly the superior student. In order, however, to understand with any precision his abilities, it is desirable to consider first the nature of the measuring instruments employed and the wide range of performance exhibited on these tests by physics students in general.

Aims of the present study

The following questions indicate the types of analysis that have been made of the data gathered in the 1936–37 testing program. While the results are only suggestive of the characteristics of scholastically able students and lack the wealth of detail that adequate description would necessitate, still they serve to focus attention on the significance of the superior student. Tests have one main purpose, and that is to reveal the existing situation with as great fidelity as present technics allow. Each participating college thereby gains a broader perspective on its students without in any way stereotyping its own course or curtailing freedom to experiment with new approaches.

1. What is the range in achievement in the major divisions of physics among students completing an introductory college course in this field? Specifically, how high must a student place on these tests in order to rank among the highest 10 or 25 percent of college students throughout the country on the examinations?

2. What particular items are known only by the best students in physics courses? Are some types of questions more efficacious than others in distinguishing between good and poor physics students?

3. Where are superior physics students found? Do some institutions have significantly larger proportions of able physics students than others? Are any existing differences

TABLE I. *Participating institutions.*

Alabama
Birmingham Southern College
Talladega College
University of Alabama

Arizona
Arizona State Teachers College, Flagstaff*
University of Arizona

Arkansas
Arkansas Polytechnic College
College of the Ozarks
Dover Consolidated High School
University of Arkansas*

California
Bakersfield Junior College*
Kern County Union High School and Junior College
Long Beach City High School District
Occidental College*
Pacific Union College
Pasadena Junior College*
San Bernardino Valley Junior College*
Santa Ana Junior College
Southern California Junior College
University of Redlands*
Whittier College*

Colorado
Colorado College

Connecticut
Connecticut State College*
United States Coast Guard Academy*
Wesleyan University*

District of Columbia
Catholic University of America
Georgetown College*
Wilson Teachers College

Florida
Florida Southern College
University of Florida*

Georgia
Georgia School of Technology
Georgia State College*

Illinois
Armour Institute of Technology
Aurora College*
Eastern Illinois State Teachers College*
Greenville College
Herzl City Junior College*
Illinois College
Illinois State Normal University
Illinois Wesleyan University
James Millikan University*
Joliet Junior College*
Lake Forest College*
La Salle-Peru-Oglesby Junior College*
Lincoln College
Loyola University
Morton High School and Junior College
Rockford College
Shurtleff College
Thornton Junior College
University of Chicago*
University of Illinois*
Western Illinois State Teachers College
Wheaton College
Wilson Junior College

Indiana
Butler University
Goshen College
Indiana State Teachers College*
Manchester College*
Purdue University
St. Mary of the Woods College

Iowa
Central College*
Drake University
Fort Dodge Junior College*
Luther College
Parsons College
St. Ambrose College
Simpson College

Kansas
Baker University*
Bethany College
Bethel College
College of Emporia*
Friends University*
Hutchinson Junior College
Parsons Junior College
St. Benedict's College
University of Kansas*

Kentucky
Asbury College*
Berea College*
Eastern Kentucky State Teachers College*
Nazareth College, Louisville
Nazareth Junior College, Nazareth
University of Louisville*

Louisiana
Centenary College*
Louisiana State University

Maine
Bates College*
Colby College*
University of Maine*

Maryland
St. John's College
Western Maryland College

Massachusetts
Amherst College
Clark University
Simmons College*

Michigan
Bay City Junior College
Catholic Junior College
Central State Teachers College*
Flint Junior College*
Highland Park
Jackson Junior College
Kalamazoo College
Michigan State College
Michigan State Normal College
Northern State Teachers College
Olivet College*
Port Huron Junior College*
University of Detroit
University of Michigan
Western State Teachers College

Minnesota
College of St. Thomas
Duluth Junior College*
Ely Junior College
Eveleth Junior College
Hamline University
Hibbing Junior College*
Macalester College
Rochester Junior College*
St. John's University
St. Mary's College*
St. Olaf College
State Teachers College, Mankato*
State Teachers College, Moorhead
State Teachers College, Winona*
Virginia Junior College

Mississippi
Mississippi College

Missouri
Kemper Military School
Lindenwood College
Missouri School of Mines
University of Missouri*
Washington University*
Wentworth Military Academy

Montana
Montana State College*

Nebraska
Doane College
Municipal University of Omaha
Nebraska Central College
Nebraska Wesleyan University*
State Teachers College, Kearney
Union College
University of Nebraska*
York College

New Jersey
New Jersey State Teachers College
St. Peter's College*
State Teachers College, Trenton

New Mexico
New Mexico Normal University
New Mexico A. & M. College
University of New Mexico

New York
Bard College*
Barnard College, Columbia University
Bushwick High School
Canisius College
Colgate University*
College of the City of New York
Columbia University
Elmira College
Hamilton College
Hunter College*
Knox School
Niagara University
Skidmore College
Syracuse University*
Union College*
University of Rochester*
Vassar College

North Carolina
Duke University*
Guilford College

North Dakota
Jamestown College*
North Dakota School of Forestry*
State Teachers College, Dickinson
State Teachers College, Minot
University of North Dakota

Ohio
Antioch College
Ashland College
Baldwin Wallace College*
College of Mt. St. Joseph-on-the-Ohio
Dayton Y. M. C. A. Junior College
Fenn College*
Findlay College
Heidelberg College
John Carroll University
Marietta College
Miami University
Mount Union College
Ohio University*
University of Cincinnati

Oklahoma
Altus Junior College
University of Oklahoma*

Oregon
Linfield College
Reed Institute

Pennsylvania
Albright College
Allegheny College*
Alliance College*
Bryn Mawr College
California State Teachers College
Elizabethtown College
Franklin and Marshall College
Geneva College*
Haverford College*
Immaculata College
Juniata College
Lafayette College*
Lincoln University
Moravian College
Muhlenberg College
Pennsylvania College for Women
Pennsylvania State College*
St. Francis College
St. Joseph's College*
St. Thomas College*
St. Vincent College
Swarthmore College*
Thiel College
University of Pennsylvania*
Ursinus College
Washington and Jefferson College
Wilson College*

South Carolina
Limestone College
State A. &. M. College

South Dakota
Augustana College
Columbus College
South Dakota State College
University of South Dakota*

Tennessee
Hiwassee College
Lambuth College
Lincoln Memorial University
Southwestern College
Tennessee Wesleyan College*
Union University*

Texas
Amarillo College
Brownsville Junior College
Paris Junior College*
Texas Christian University*

Utah
Snow College
University of Utah*

Vermont
Green Mountain Junior College*
Vermont Junior College*

Virginia
Hampton Institute
Lynchburg College
Sweet Briar College
University of Virginia*

Washington
College of Puget Sound
University of Washington
Walla Walla College*
Washington State College
Western Washington College of Education*
Whitworth College

West Virginia
Concord State Teachers College

Wisconsin
Lawrence College*
Milton College
St. Norbert College
State Teachers College, La Crosse
State Teachers College, Milwaukee
State Teachers College, River Falls
State Teachers College, Superior*

Canada
North Vancouver High School
St. Francis Xavier College*
University of British Columbia*

* The present report is limited to returns received from the starred colleges. Other colleges did not return scores in time for inclusion in this report.

among colleges in this respect related to the general type of institution attended?

4. What is the general character of the superior group with respect to sex and professional goal?

5. Does previous study of physics in secondary school contribute to superiority in college in this field? Are differences between those who have had a previous course in this field and those without earlier formal instruction greater for the pre-study tests or for examinations administered after the college course has been completed?

Scope of the examinations

Examinations that really measure important outcomes of physics instruction must be constructed by those who are thoroughly familiar with the field. The Committee has carefully guarded its examining program against the unhappy experience of teachers in certain fields who have had to work with tests formulated almost entirely by educationists. While technical assistance in test construction is required in order to obtain valid and reliable measuring instruments, the content of these physics tests has been entirely determined by physicists who are actually teaching physics to college students.

Instead of following the usual plan of providing a single examination to cover the entire year's work, the physics committee has each year prepared separate tests in the major divisions of a first course in college physics. Included in the 1936–37 examination program were separate tests, requiring 20 to 60 min. for administration, and covering mechanics, heat, sound, light, electricity, and modern physics. This plan has had at least two major advantages. It has allowed a desirable flexibility to each institution to administer only as many as were suitable for the first course as given in a particular college and to give them in an order that corresponded with the treatment of these topics; and it has provided more specific indications of how well each of these major divisions has been mastered, so that further study and review may be intelligently planned.

Pre-tests of comparable difficulty to those administered at the conclusion of regular study have made it possible for instructors to take into account wide differences with respect to students' background in this field. New forms of both pre- and post-study tests are issued each year, assuring a continuing supply of fresh testing material. Since these examinations remain of comparable difficulty, accurate comparisons may be made from year to year of the general quality of the students enroled in physics courses in a particular institution. Instructors may also determine on this basis whether certain promising reorganizations in teaching actually do result in more thorough mastery of physics.

After examinations have been carefully constructed, there still remains the problem of norms. Physicists recognize the importance of relative measures of success probably more keenly than any other academic group because they face constantly the critical problem of defining suitable standards in their own field. The traditional method of testing is most vulnerable at this point because subjective tests differ so much in scope and difficulty that the percentage correct on one examination very seldom indicates the same quality of performance as a corresponding percentage correct on another test. In the place of this variable standard, the physicists have substituted tables that show the relative achievement of thousands of students on the same comprehensive, objectively-graded tests. The importance of this cooperative approach is most evident in the case of the superior student, for while an individual may be considered as above average for his particular class, the true extent of his ability is often unrecognized until results on a broad-gauged examination throw into striking relief the actual degree of uniqueness of such talent among physics students in general.

These tests are not designed to measure all the outcomes of college physics instruction, for they do not probe laboratory skills, or attempt to determine directly how critical students are in their approach to problems, or how far they transfer habits of rigorous thinking in this area to general scientific or social problems. The present examinations are more modest in their scope, for they have been formulated to measure relatively definite and frequently stressed factual knowledge, with the individual items so framed that a reasoned understanding of such materials is required rather than sheer rote memorization. Unless a student possesses a clear comprehension of these cue concepts and principles, however, it certainly appears unlikely that he will evaluate intelligently the work of others or make fruitful original approaches to problems.

The identification of able students

The fact of variation in performance, reflected year after year in the spread of college physics grades from unconditional failures to grades of "A" that remain only imperfect expressions of the superiority that the instructor senses, is shown in arresting fashion by results on these tests. On each of the six examinations in physics, students who have had much the same formal instruction differ markedly in their actual understanding of the materials presented. An illustration of the wide dispersion in scores is given in Table II for the first test in the series, the 60-min. examination in mechanics. The average score on this test is 17.1, but individual students deviate widely from this point, ranging in their achievement from 0 to 49.

Since raw scores differ in numerical size from test to test, being usually greater for longer than for shorter examinations, percentile ranks have

TABLE II. *Distribution of scores for men students on the mechanics test, including the percentile equivalent for each raw score.*

Raw Score	No. of Cases	Cumulative Frequency	Percentile Rank*	Raw Score	No. of Cases	Cumulative Frequency	Percentile Rank*
49	3	4188	100	24	113	3425	80
48	2	4185	99	23	134	3312	77
47	1	4183	99	22	165	3178	74
46	3	4182	99	21	139	3013	70
45	3	4179	99	20	171	2874	66
44	2	4176	99	19	194	2703	62
43	8	4174	99	18	197	2509	58
42	9	4166	99	17	174	2312	53
41	10	4157	99	16	192	2138	49
40	14	4147	98	15	198	1946	44
39	12	4133	98	14	203	1748	39
38	9	4121	98	13	185	1545	34
37	18	4112	98	12	237	1360	29
36	22	4094	97	11	159	1123	25
35	34	4072	97	10	181	964	21
34	21	4038	96	9	147	783	17
33	34	4017	95	8	137	636	14
32	40	3983	95	7	127	499	11
31	46	3943	94	6	99	372	8
30	57	3897	92	5	64	273	6
29	80	3840	91	4	59	209	4
28	76	3760	89	3	49	150	3
27	78	3684	87	2	32	101	2
26	82	3606	85	1	23	69	1
25	99	3524	83	0	46	46	1

* The percentile values given here represent the rank of the middle individual in the group obtaining a particular score. Thus the percentile rank of 18 which is given for a raw score of 9 has been obtained by adding half of the 147 cases making scores of 9 to the 636 cases falling below this point, and computing the percentage that this sum (759.5 cases) is of the total population (4188). Some of the values given here differ slightly from those reported in Table III, the present ones being more exact. Only certain specified percentiles are included in the other table, which necessitated a reporting of the nearest raw score value.

been assigned to allow comparisons with other test results. These percentile scores, which are also presented in Table II, are easily interpreted, for they simply indicate the percentage of the entire tested population that achieved at a level below or equal to a given score. Thus a raw score of 11 on the mechanics test has a percentile equivalent of 25, showing that this quality of performance is equal or superior to that of 25 percent of all students tested. While these percentile scores extend from 1 to 100, they bear no relation to the older percentage system of grading papers. By definition, for example, as many students make percentile scores below 25 as above 75.

More complete information concerning performance on these tests is presented in Table III where percentile equivalents are given for all scores on the single examinations and on various combinations of tests reported by participating colleges. Again taking the results on the first examination in mechanics as illustrative, we note that some students sit through all the lectures and laboratory work concerned with this topic and yet emerge with only the crudest notion of what was being discussed. Twenty-five percent of all the college students who took this examination after several weeks of study made scores lower than 11 out of a total possible score of 60. This level of performance is inferior to what many students exhibit before they have had any college training at all, as later results will indicate.

The encouraging aspect is found at the upper end of the scale, where 25 percent of the students obtained scores exceeding 22, and an elect 10 percent surpassed the quality of achievement denoted by a score of 28. These able students have too often sat in classes where instruction was geared to the mediocre or inferior student, and yet they have succeeded in gaining a clear insight into some of the most difficult principles embodied in these tests. What constitutes a superior level of performance for any individual institution must be determined by the local physics department; the present results simply furnish broad thresholds to aid in the definition of criterions suited to the needs of each participating college and to the transfer of credits from institution to institution.

While these total scores serve to identify both the very able and the handicapped students in physics, it is interesting to explore the specific understandings that are most characteristic of the superior student. Detailed studies of this type have been made for the present tests, and the results are given in Tables IV and V. Individual items have varied greatly in difficulty, as these statistics indicate. Some questions have been so easy that over 85 percent of all tested students in introductory physics courses have selected the correct answer, while in other cases the proportion of successful students is as low as 5 percent. These results not only provide significant information on the achievement of students, but they also constitute to some degree an objective indication of the points of least and greatest emphasis in current physics courses.

A sampling of the most difficult items has been included in order to illustrate not only the general character of these tests but also the type of item that possesses sufficient altitude to test adequately the more brilliant student. One item has been selected for this purpose from each of the six separate examinations.

Most Difficult Items

M 53. If a steel rod with a cross-sectional area of 1 in.^{2} is supporting 3000 lb., the elongation of the rod is 0.02 percent. Its Young's modulus is therefore, in lb./in.^{2}, about (1) 150,000, (2) 60, (3) 6×10^5, (4) 15×10^6, (5) 7.5×10^7 .....( )

H 27. If a steam engine working between the temperatures of 127°C and 27°C uses $\frac{1}{3}$ of its power to overcome friction, its efficiency is about (1) 8.7%, (2) 12.8%, (3) 22.2%, (4) 30%, (5) 66.6%.....( )

S 14. When a cog wheel with 40 teeth rotates 5 times per second, a card held against it produces a sound exactly three octaves below that of a certain whistle. The number of vibrations per second of the whistle is therefore (1) 200, (2) 600, (3) 800, (4) 1200, (5) 1600.....( )

L 34. A spectroscope that cannot quite resolve the sodium D lines would just fail to detect the Doppler effect in the light from a star moving away from the earth with a speed whose ratio to the speed of light is (1) 1/10, (2) 1/100, (3) 1/1,000, (4) 1/10,000, (5) 1/100,000 .....( )

E 44. A sinusoidal alternating current measured as 1 amp. is completely rectified to give a unidirectional current. The current will be still 1 amp. if measured by (1) an ordinary d.c. ammeter, (2) a hot-wire meter, (3) the

TABLE III. *National percentiles for the 1937 Cooperative Physics Tests for men college students.**

	M	H	S	M+H	M+H+S	L	E	MP	L+E	L+E+MP	
No. Cases	4188	3997	3468	3838	2939	3469	4057	1956	3368	1731	
Mean†	17.1	12.1	7.0	29.0	36.4	10.4	15.7	5.7	26.0	32.3	
Sigma†	8.5	5.9	3.3	13.2	15.5	5.5	8.2	3.5	12.3	14.5	
Percentile											Percentile
100	49	30	16	79	95	35	45	17	71	84	100
99	41	27	15	64	78	25	37	14	58	70	99
98	37	25	14	60	72	23	34	—	54	66	98
97	35	24	—	57	69	22	33	13	52	63	97
96	34	23	13	55	67	21	32	—	50	61	96
95	32	—	—	53	64	—	31	12	48	59	95
94	31	22	12	52	63	20	30	—	47	57	94
93	—	—	—	51	62	19	29	—	46	56	93
92	30	21	—	49	60	—	—	11	45	55	92
91	29	—	—	48	59	—	28	—	44	54	91
90	—	20	—	47	58	18	27	—	43	53	90
88	28	—	11	45	56	17	26	10	41	51	88
86	27	19	—	43	54	—	25	—	40	49	86
84	26	18	—	42	52	16	24	—	39	47	84
82	25	—	10	41	51	—	—	9	37	45	82
80	24	17	—	40	49	15	23	—	36	44	80
75	22	16	—	37	46	14	21	8	34	41	75
70	21	15	9	35	44	13	20	—	32	39	70
65	20	14	—	33	41	12	18	7	30	37	65
60	19	13	8	31	39	11	17	—	28	35	60
55	17	—	—	29	37	—	16	6	26	33	55
50	16	12	7	28	35	10	15	—	25	31	50
45	15	11	—	26	33	9	14	5	23	29	45
40	14	10	6	24	31	—	13	—	22	27	40
35	13	9	—	23	29	8	12	4	20	25	35
30	12	—	5	21	27	7	11	—	18	24	30
25	11	8	—	20	25	—	10	3	17	22	25
20	10	7	4	18	23	6	9	—	15	19	20
18	9	—	—	17	22	—	8	—	14	18	18
16	—	6	—	16	21	5	—	2	—	17	16
14	8	—	—	15	20	—	7	—	13	16	14
12	—	5	3	14	19	4	6	—	12	15	12
10	7	—	—	13	18	—	—	—	11	14	10
9	—	—	—	12	17	—	—	—	10	—	9
8	6	4	—	—	16	—	5	1	—	13	8
7	—	—	2	11	15	3	—	—	9	—	7
6	5	—	—	10	14	—	4	—	—	12	6
5	—	3	—	9	13	—	—	—	8	11	5
4	4	—	—	8	12	2	3	—	7	10	4
3	3	2	1	7	11	—	2	—	6	9	3
2	2	1	—	6	9	1	1	—	5	8	2
1	1	—	—	4	6	—	—	—	4	6	1

* The scales are based upon returns for students tested after studying the various topics, and show percentiles, calculated from the distributions of scores available at the time of computation. Each score in each column shows the value closest to the percentile indicated in columns at the extreme right or left of the page. For example, the bottom entry in the column for total score on M+H indicates that all raw scores of 4 or below have a percentile value of 1; all scores of 6 have a percentile value of 2; and all scores above 64 have a percentile value of 100. Since colleges used varying combinations of tests, the numbers of cases differ from column to column.

† The mean here is simply the arithmetic average, while the standard deviation or "sigma" is a well-recognized statistical constant which indicates the variability of the scores in a given group. The standard deviation is defined by the equation $\sigma=(\Sigma(d^2/n))^{\frac{1}{2}}$ where d represents a deviation from the mean and n the number of cases. Thus the value of 8.5, reported as the standard deviation for the mechanics test, shows that about two-thirds (68.3 percent) of the cases in a normal distribution would be found within this distance of the mean, or between 8.6 (17.1−8.5) and 25.6 (17.1+8.5). The smaller the standard deviation on a given test, the more concentrated are the cases around the average.

electrolytic deposition of silver, (4) any method, (5) the e.m.f. generated by self-induction.....( )

MP 18. The original Balmer series was (1) known before the construction of the first grating, (2) known to Sir Isaac Newton, (3) discovered by experiment before the electron was known, (4) found in the spectrum of mercury vapor, (5) discovered since 1920.....( )

Difficult questions must be included in any examination if good students are to be adequately tested, but this characteristic alone does not insure a satisfactory examination. It is also important that the individual items possess validity, or the capacity to discriminate be-

TABLE IV. *Difficulty and validity indices for each item in the M, H, S, L, E, and MP 1937-B test forms.*

	Mechanics		*Heat*		*Sound*		*Light*		*Electricity*		*Mod. Phys.*	
ITEM NO.	DIFF.	VAL.	DIFF.	VAL.	DIFF.	VAL.	DIFF.	VAL.	DIFF.	VAL.	DIFF.	VAL.
1	59*	4†	87	4	67	7	79	5	87	4	74	4
2	17	1	68	7	79	3	80	2	65	5	73	3
3	86	3	24	9	57	8	76	4	85	5	65	6
4	35	6	71	3	48	6	72	6	56	3	89	5
5	70	5	56	4	32	4	70	2	49	4	55	5
6	43	5	37	3	83	5	75	5	78	5	60	7
7	16	2	66	6	36	6	74	4	64	6	46	5
8	30	4	54	3	79	9	55	5	62	5	46	5
9	45	5	39	7	68	5	40	2	44	7	41	4
10	61	1	73	4	34	6	63	6	69	4	27	3
11	30	5	46	5	31	2	54	5	71	5	32	4
12	14	3	39	5	75	7	39	4	56	4	37	5
13	67	4	51	6	35	5	41	2	67	4	44	7
14	32	4	67	3	21	5	52	3	66	6	34	6
15	18	3	57	6	68	5	50	4	42	4	29	7
16	38	3	70	5	65	6	55	3	59	2	18	3
17	31	4	50	6			30	2	53	4	30	6
18	71	7	33	3			51	2	58	6	11	5
19	24	5	55	5			36	6	39	5	16	6
20	65	4	53	5			20	4	62	5		
21	33	4	76	6			48	3	58	4		
22	74	3	23	9			29	3	69	8		
23	22	2	28	5			34	4	47	7		
24	46	5	34	4			26	4	52	5		
25	83	2	38	4			26	1	34	4		
26	22	5	51	4			33	4	21	3		
27	55	3	11	2			31	5	48	6		
28	62	5	33	5			16	1	29	5		
29	65	3	55	5			16	2	44	6		
30	17	5	49	6			22	4	34	4		
31	16	5					24	4	48	5		
32	57	5					19	4	34	4		
33	54	3					26	7	34	5		
34	81	7					4	5	22	3		
35	35	6					30	4	39	4		
36	34	5							59	4		
37	78	4							19	4		
38	71	6							15	2		
39	53	5							32	2		
40	29	6							35	5		
41	22	6							30	4		
42	7	5							16	5		
43	77	4							8	1		
44	17	3							8	3		
45	9	5							39	3		
46	53	5										
47	21	3										
48	61	4										
49	21	0										
50	57	5										
51	62	4										
52	9	3										
53	7	5										
54	38	2										

* A difficulty value of 59 indicates that 59 percent of the students gave the correct answer to this particular item.

† A validity index for an item is a number whose value indicates how well the item differentiates between able and poor students. It is defined by the equation $(x_u - x_l)/0.25$ where x_u is the deviation from the mean corresponding to the proportion of successes on a given item for students who ranked in the upper 27 percent of the population on the entire test, and x_l is the homologous deviation for students ranking in the lower 27 percent of the population. These deviation values may be obtained from a table of the normal probability integral. The present validity index of 4 shows that the item possesses differentiating power to a significant degree. Thus if 85 percent of the students who ranked in the upper quarter of the group on the examination gave the right answer to this particular item, correct responses would be expected from only about 50 percent of those in the lowest quarter. The higher the numerical size of the index, the more pronounced the difference between these extreme groups in their performance on a specific item.

tween groups of students who are known to differ in their physics performance. Each item constitutes a miniature test, and those questions are best that most effectively separate students into their appropriate ability levels. The validity values of the present items are also presented in Table IV, and have been obtained by determining the extent to which each particular item discriminates between the highest and lowest scoring students on the entire examination. A validity index of 0 indicates that the item lacks testing value, for as many poor as good students answered it correctly. It is gratifying to note that almost three-fourths of all the items included show values of 4 or more, corresponding to a difference of at least one standard deviation between the upper and lower groups.[1] A selection of the most valid items is included to show the characteristics of questions that possess unusual discriminating power.

Items Having Highest Validity

M 18. When energy is used to pull down a spring roller window shade which is in good working condition, most of the energy is (1) transformed to kinetic energy of rotation, (2) transformed to kinetic energy of translation, (3) transformed and lost, (4) transformed to momentum, (5) transformed to potential energy.....( )

[1] To make more nearly comparable the percentage differences for items of all degrees of difficulty, the results are expressed in quarter-sigma units. For an illustration of the meaning of a validity index of 4 in terms of percentage differences, see second footnote in Table IV.

TABLE V. *Summary of difficulty and validity indices, showing number of questions within a given range of difficulty or possessing a specified degree of validity.*

DIFFICULTY	M	H	S	L	E	MP
85–89	1*	1			2	1
80–84	2		1	1		
75–79	2	1	3	3	1	
70–74	4	3		3	1	2
65–69	3	3	4		5	1
60–64	4			1	3	1
55–59	4	4	1	2	6	1
50–54	3	5		4	2	
45–49	2	2	1	1	4	2
40–44	1			2	3	2
35–39	4	4	2	2	4	1
30–34	6	3	3	5	6	3
25–29	1	1		4	1	2
20–24	6	2	1	3	2	
15–19	6			3	3	2
10–14	1	1				1
5– 9	4				2	
0– 4				1		

VALIDITY	M	H	S	L	E	MP
9		2	1			
8			1		1	
7	2†	2	2	1	2	3
6	5	6	4	3	5	4
5	18	8	5	6	13	6
4	11	6	1	12	15	3
3	11	5	1	4	5	3
2	4	1	1	7	3	
1	2			2	1	
0	1					

* This indicates that one question on the mechanics test was answered correctly by 85 percent or more of the students.

† Two questions on the mechanics test showed validity indices of 7. Such items distinguish very clearly between superior and inferior students. For a more complete explanation of the meaning of this term, see the footnote in Table IV.

TABLE VI. *Distributions of college averages.**

	Mechanics+Heat							*Mechanics+Heat+Sound*							*Light+Electricity*							*Light+Elec.+MP*							
GROUP	1	2	3	4	5	6	TOTAL	1	2	3	4	5	6	TOTAL	1	2	3	4	5	6	TOTAL	1	2	3	4	5	6	TOTAL	
National Percentiles (Men)																													National Percentiles (Men)
88–91								1						1	1						1	1						1	88–91
84–87	1†		1			1	3			1				1			2			1	3							84–87
79–83													1	1	1		1			1	3					1	1	79–83
72–78	1		2	1	2	2	8	1			2	1		4			1	1		1	3	1		1			2	72–78
66–71	1	1	3	1	1	2	9	1	1	3			1	6	2	1	2				5		1	2			3	66–71
58–65			4	1	1	1	7	2		7	1			10	3		9	1	1	3	17	1		4	4	1	7	58–65
50–57	2		5			2	9			5		1	1	7			2	2	1	3	8	1		1		2	4	50–57
42–49	1	1	8	1		4	15	1	1	5			3	10			8	1		2	11			5	2	1	3	11	42–49
34–41		1	6	2		1	10	2		4	1		2	9		1	6	2		3	12		1	3	1			5	34–41
27–33	3	1	4	1		2	11	1	3	4	1		2	11	2		4			1	7	2		2			1	5	27–33
21–26		1	1				2			3				3	1	2	1				4		1					1	21–26
16–20			1				1										2				2			1				1	16–20
12–15	1						1										1				1								12–15
8–11	1		1				2			1				1	1						1								8–11
6– 7																													6– 7
Total	11	5	36	7	4	15	78	9	5	33	5	2	10	64	11	4	39	7	2	15	78	6	3	18	5	1	8	41	

* The institutional means on four combinations of the post-study tests are here distributed in terms of national percentiles for men, presented and explained in Table III. The first six distributions in each section are for types of institutions as follows:

1. Men's Liberal Arts Colleges
2. Women's Liberal Arts Colleges
3. Coeducational Liberal Arts Colleges
4. Teachers Colleges
5. Agricultural and Engineering Colleges
6. Junior Colleges

The last column in each section gives the distribution of averages for all types of institutions combined.

† The following interpretation of the first entry illustrates the general plan followed in this table. It is evident from this figure that the average for one of the eleven men's liberal arts colleges that returned scores was superior to the achievement shown by from 84 to 87 percent of all tested students. The intervals used in presenting these results have been so modified that they correspond approximately to a sigma scale. Distances expressed in standard deviation units tend to be equal in all parts of the scale, a condition which does not hold for percentile scores. An explanation of the term "standard deviation" or "sigma" is given in the second footnote in Table III.

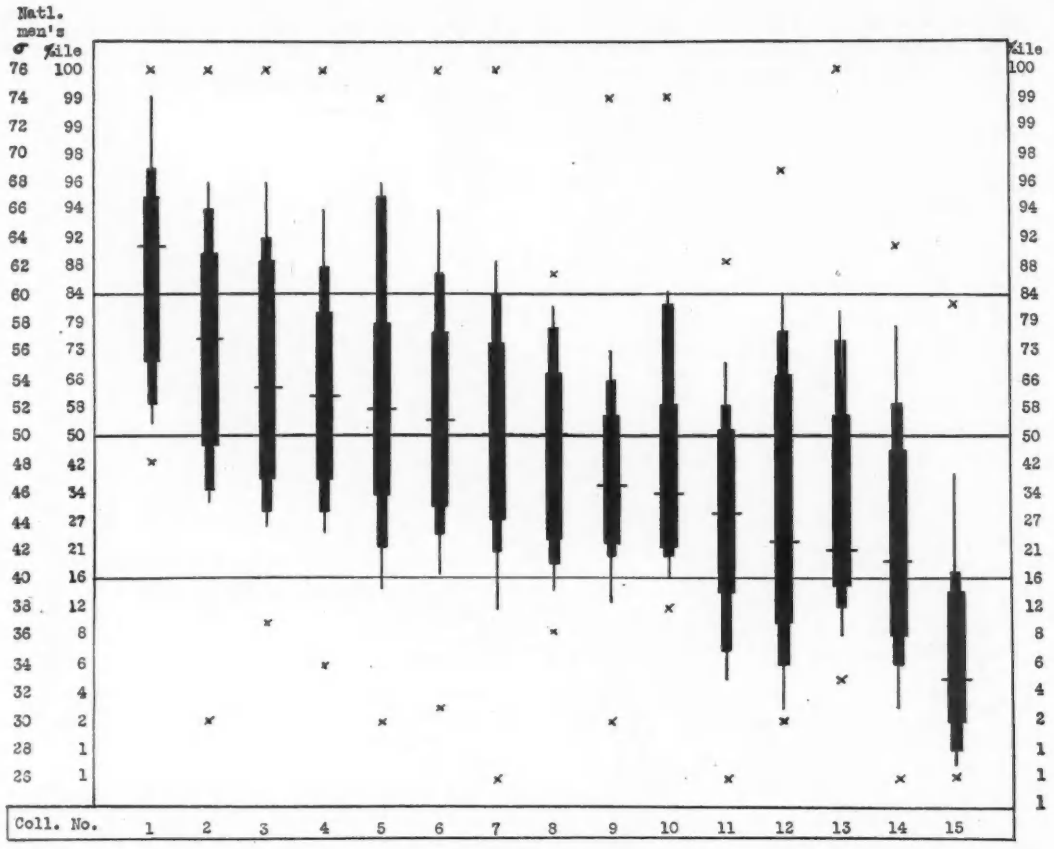


FIG. 1. Variability in achievement as measured by the combined scores on M, H, and S. Each of the bars represents an individual college. The wide portion of each bar represents the range of scores of the middle half in each college. The narrow parts extend to the 16th and 84th percentiles in each college, i.e., one standard deviation above and below the mean. The lines at the ends extend down to the 10th percentile and up to the 90th percentile. The crosses below the bars represent the lowest scores, and those above, the highest scores in the several colleges (the range). The short cross-line at the middle of each bar represents the median score of the college. The middle horizontal line in this chart shows the national median for men students, and the other two lines are at the 16th and 84th percentiles of the national distribution. Since distances expressed in standard deviation units tend to be equal in all parts of the scale, the present percentile scores have been grouped in intervals that correspond approximately to a sigma scale.

H 22. Two similar "black bodies," *A* and *B*, are at temperatures of 2700° absolute and −3°C, respectively. If they are each surrounded by objects at absolute zero, theoretically *A* should radiate (1) just as fast as *B*, (2) 10 times as fast as *B*, (3) 100 times as fast as *B*, (4) 10^4 times as fast as *B*, (5) nearly 2700 times as fast as *B*....( )

S 8. Two beats per second will be produced by a pair of tuning forks having respective frequencies of (1) 235 and 470 per sec., (2) 347 and 348 per sec., (3) 620 and 620×2 per sec., (4) 734 and 736 per sec., (5) 1056 and 1060 per sec.....( )

L 33. A caustic is best produced by light reflected from a (1) plane mirror in a parallel beam, (2) large concave spherical mirror with a small source at the center of curvature, (3) parabolic reflector with a small source at the focus, (4) semicylindrical concave surface in a parallel beam, (5) plane mirror in a diverging beam.....( )

E 22. The current in a simple series circuit is 5.00 amp. When an additional resistance of 2 ohms is added, the current is 4.00 amp. The resistance of the original circuit is, in ohms, (1) 10, (2) 8, (3) −10, (4) 1.2, (5) 12..( )

MP 6. The three characteristics of an electric circuit that determine its frequency of oscillation are (1) inductance, resistance, and impedance, (2) inductance, capacitance, and resistance, (3) capacitance, potential, and length, (4) potential, current, and resistance, (5) resistance, power, and e.m.f.....( )

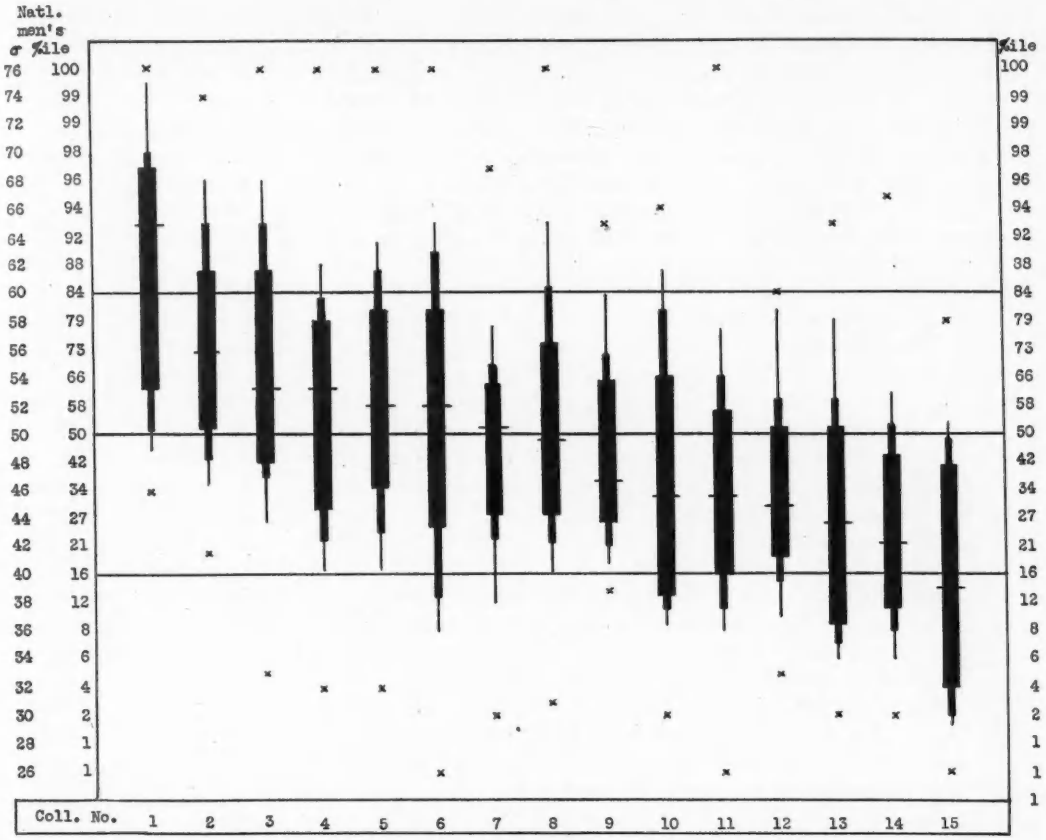


FIG. 2. Variability of achievement as measured by combined scores on L, E, and MP. To be read in the same manner as Fig. 1.

Correlates of superiority in physics

The preceding materials have indicated rather clearly that some students emerge from an introductory physics course with a degree of mastery that far exceeds that of the typical or average individual in colleges throughout the country. The question naturally arises as to whether their performance bears any significant relation to a number of factors that might be adduced as possible explanations of such superiority.

At the outset it should be noted that the present data are not sufficiently extensive to determine the existence of causal relationship between the factors studied and unusual performance in physics. Thus the largest value of secondary school physics may lie not so much in its direct contribution to the college course as in the fact that students who elect such a course tend to possess the interests and abilities which are also prerequisite to success in college classes in this field. Whether the relationship is causal or merely concomitant, however, it is important to know the characteristics of those students who are outstanding in their college physics achievement.

The first point investigated in this connection was the type of institution attended, to determine whether certain types were markedly superior to others in the general quality of their student performance. As the data presented in Table VI indicate, no clear-cut differences exist with

respect to the various classifications of colleges used in this analysis. The averages for some entire classes fall well below the 25th percentile in the national norms, a point exceeded by three-fourths of the total population, whereas other colleges that have the same general function show a typical level of performance that is in excess of the 75th percentile, or superior to a very large proportion of all students tested.

This variation among individual colleges is delineated in clearest fashion in Figs. 1 and 2, where the achievement of students in fifteen specially selected colleges is given. The identity of the particular institutions concerned is unknown to the members of this committee, and the results are presented simply to illustrate the wide variations in standards that exist from institution to institution. While some of these differences are due to the fact that physics courses have various prerequisites and are taken for various credits, still the extent of variation is far greater than might have been suspected by subjective estimates. The top college in Fig. 1 has as its "just average" student an individual whose performance is superior to that of 91 percent of all tested students, whereas the last institution in this hierarchy shows a typical level of achievement equal only to that displayed by the lowest 5 percent of students in general.

While institutions do differ in the extent to which they either initially attract superior students or succeed in improving the performance of mediocre individuals, it must be borne in mind that each college has some very high and some very low ranking students. Even in the lowest college presented in Fig. 1, there was one individual who was superior to over 80 percent of all the tested physics students. Every college, regardless of size or type, therefore faces the challenge offered by students of unusual ability.

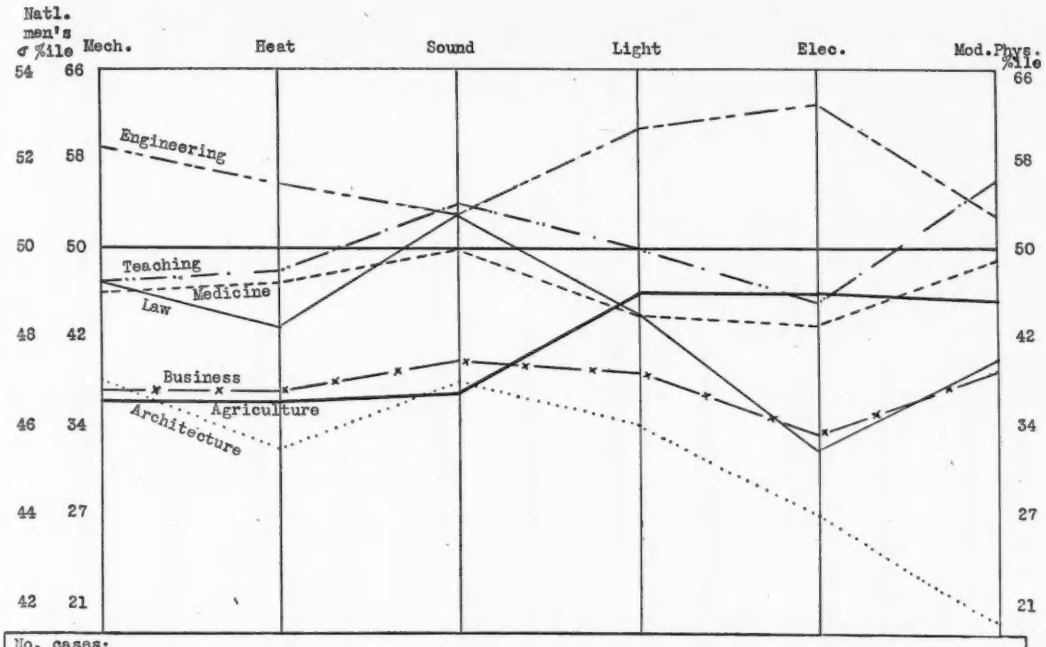
Certain differences exist between the two sexes in their average performance on the examinations, with men consistently outdistancing women. Abbreviated percentile scales for the interpretation of scores made by women students are presented in Table VII, and illustrate not only the somewhat lower performance levels shown by women but also emphasize the wide variability that exists around this average measure. Since information is lacking concerning the previous preparation of these groups in either physics or mathematics, it is impossible to draw any very definite conclusion beyond the fact that superior physics students tend to be men rather than women.

The professional goal of the student affords another clue to the characteristics of superior physics students. Bearing in mind again the fact that the present results must remain suggestive rather than conclusive because the representativeness of the sample obtained is

TABLE VII. *National percentiles for women.**

	M	H	S	M+H	M+H+S	L	E	MP	L+E	L+E+MP	
No. Cases	550	539	538	524	487	359	415	268	321	203	
Mean	13.2	9.2	6.6	22.1	28.6	8.3	12.1	4.4	19.9	23.2	
Sigma	6.7	4.4	2.9	10.0	11.8	4.6	6.8	3.3	10.1	10.6	
Percentile											Percentile
100	38	26	15	61	72	29	38	18	67	58	100
98	30	20	13	47	57	19	29	13	44	47	98
93	23	17	11	37	47	16	23	9	37	41	93
90	22	16	10	35	44	14	21	8	34	38	90
84	20	13	—	32	40	13	19	—	30	33	84
80	19	12	9	30	38	12	18	7	27	32	80
75	18	—	—	28	35	11	16	6	25	30	75
70	16	11	8	26	33	10	15	—	24	28	70
60	14	10	—	23	30	9	13	5	20	24	60
50	12	9	7	21	27	8	11	4	18	21	50
40	11	8	6	19	25	7	10	3	16	19	40
30	9	7	5	16	22	6	8	—	14	17	30
25	8	6	—	15	20	5	7	2	13	16	25
20	7	—	4	14	18	4	6	—	12	14	20
16	6	5	—	13	17	—	5	1	11	13	16
10	5	4	3	10	15	3	4	—	9	11	10
7	4	3	2	9	14	2	3	—	8	10	7
3	2	2	1	6	10	1	2	—	5	6	3
1	0	1	0	5	8	0	0	0	3	4	1

* Because of the small number of cases, the percentiles are shown in abbreviated form. The table is to be read in the same manner as Table III.



No. cases:						
Eng.	1830	1730	1366	1345	1592	902
Teach.	357	393	340	320	393	211
Med.	865	803	789	882	981	399
Arch.	38	33	27	29	31	25
Bus.	206	196	187	145	193	94
Law	62	57	54	44	61	31
Agric.	45	43	19	18	37	14

FIG. 3. Averages of professional goal groups. The data are graphed in terms of the national percentile scale for men, altered, as in Fig. 1, to conform approximately to the sigma scale. Vertical distances are, therefore, roughly comparable.

not known with precision, it is significant to know that students with certain professional objectives tend to make definitely higher average scores than other groups do.

Although the limited number of cases for certain groups precludes generalizations, the trends which appear in Fig. 3 show an interesting consistency with those presented in the reports of previous years.[2] Again the engineering group clearly surpasses all others in every division except sound and modern physics, where students interested in teaching show approximately the same level of performance. Those indicating vocational objectives relating to business, agriculture, or architecture seem to be, on the whole, relatively poorer risks in elementary physics, a reflection not only of their lesser ability or interest in this field but also probably of the more circumscribed type of physics course many of them have taken. It must be remembered, however, that these statements apply to the average performance of the entire group, and that within any given category there are individual students who deviate widely from the typical achievement of their own professional goal group.

The question of the value of secondary school study of physics is a moot one among college instructors. Some definitely prefer to give students their initial instruction in this field, arguing that the increment of factual information shown by those who have had previous formal study in secondary school hardly compensates for the work the college must do in revising naive conceptions and in building up

[2] See Am. Phys. Teacher **2** (Supplement, Sept., 1934); **3** (Supplement, Sept., 1935); and **4** (Supplement, Sept., 1936).

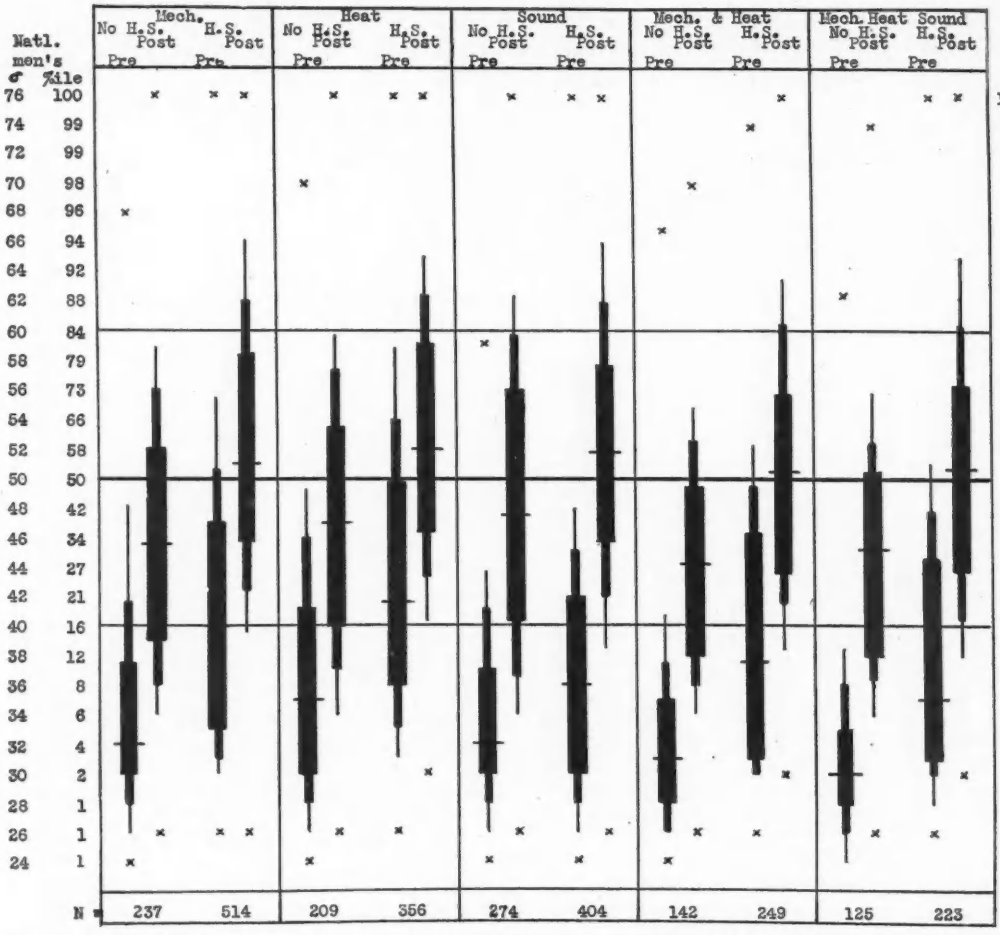


FIG. 4. Pre- and post-study comparisons for M, H, and S. The two bars at the left of each section represent distributions of scores for all students who had not studied physics in secondary school and who took the tests both before and after study. The two following bars represent the distributions of pre- and post-test scores for students who had studied physics in secondary school.

rigorous habits of thinking. Others aver that college physics often proves to be too difficult for those who have not had secondary school study, and therefore they definitely encourage efforts to set secondary school physics as a prerequisite for college study. The way out of this confusion would seem to lie in a critical examination of what students with and without previous secondary school instruction actually do know concerning fundamental elements in college physics.

Such a realistic approach, which stresses demonstrable knowledge rather than hoped-for changes suggested by analyses of textbooks and syllabi, has been made for the present data. The number of cases having both pre- and post-study tests was unfortunately rather small, but the fact that the same trends have appeared from year to year indicates that confidence may be placed in the present findings, which are shown graphically in Figs. 4 and 5. Without exception, the group with previous secondary school study surpasses the average performance of those students who begin physics at the college

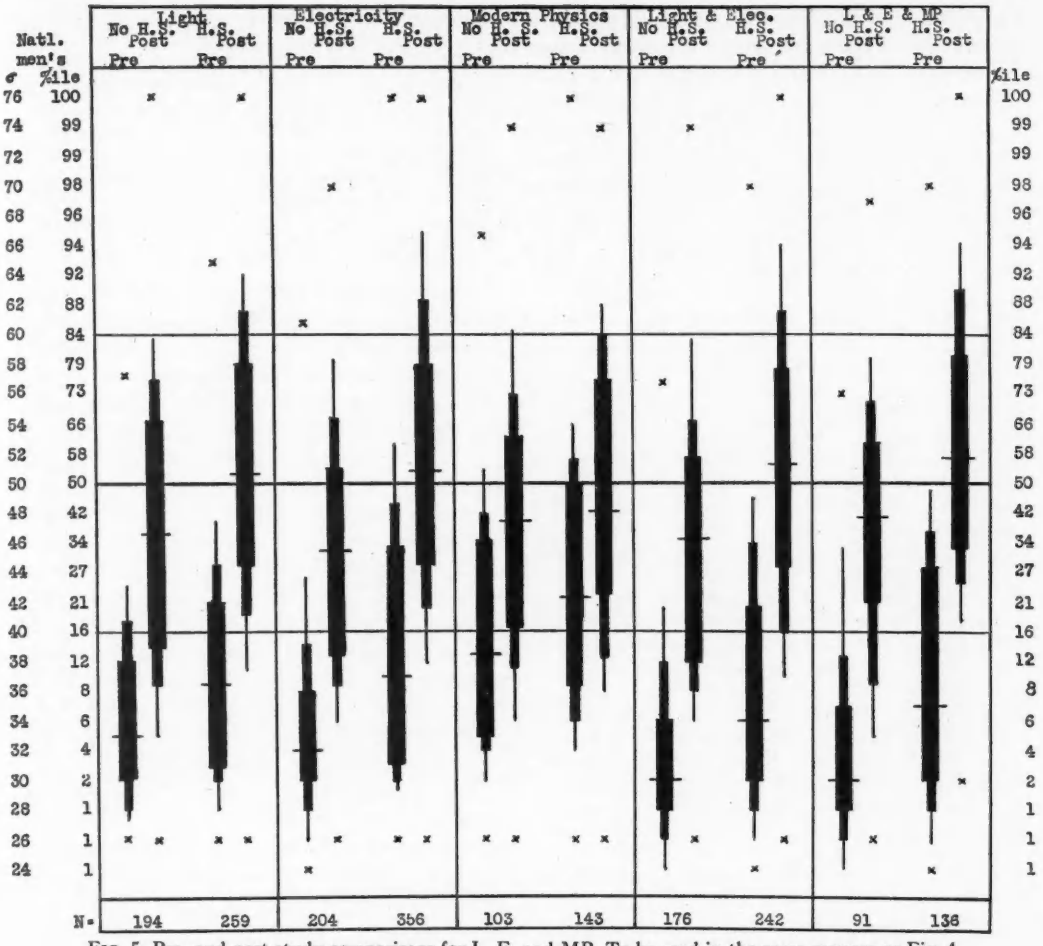


FIG. 5. Pre- and post-study comparisons for L, E, and MP. To be read in the same manner as Fig. 4.

level. The differences are smallest with respect to modern physics, where the secondary school physics group begins with somewhat of an advantage but shows only the slightest edge at the conclusion of the course over the group without previous secondary school study.

It is interesting to note that the average student with previous instruction maintains his initial superiority through the period of college instruction, so that he concludes his first college course with a better grasp of basic principles than his colleague does for whom everything was new. The present data are insufficient to indicate the extent to which this is due to the direct contribution made by earlier physics teaching and the extent to which it may be attributed to the superior type of student attracted by secondary school physics courses. From the standpoint of practice, however, the findings are clear. Superiority in college physics may be more confidently expected from those with prior study in this field, and therefore they need to be constantly confronted with problems that really challenge their background and preparation.

Implications

The wide variability that exists within every classification of students considered in the present study possesses important implications

for college physics teaching. Only a few of the more salient findings of this investigation are restated here, with a suggestion of certain problems that require further study. It is hoped that the same type of cooperative effort that has proved so helpful in revealing the outcomes of college physics study may also be enlisted to aid individual instructors in their search for better ways of meeting the needs which have been made evident by these searching comprehensive tests.

1. College introductory physics courses vary considerably from institution to institution in the outcomes shown by students. Evidence also exists, which will be published in a later report, that much the same relative positions are maintained by colleges from year to year. Such persistent differences deserve study with a view to determining their cause. Investigations are particularly needed in which college physics achievement is viewed in the light of the general scholastic aptitude of the student body, so that more analytic studies may be made of those situations where instruction seems to have been peculiarly efficacious. While every institution tested possesses some superior students, the significantly larger proportions found in certain colleges make it desirable to isolate the factors that contribute to distinctive achievement in this field.

2. Much material, that has been generally accepted as basic to all future courses in this field, is very imperfectly understood by students completing a first course. The "half-learning" revealed by these tests indicates in arresting fashion that even in the most highly selective institutions a necessity exists for strengthening the students' comprehension of those fundamental facts and concepts that are the indispensible substratum for critical or creative thinking in advanced physics courses. While superior students far outdistance others in their mastery of important principles, a sharpening of the focus of college instruction should pay even richer rewards here than it would in the case of the more mediocre students.

3. Individual students vary so widely that there is definite need to use the most accurate methods available for classifying students and for organizing instruction. Certain groups, based on sex, professional goal, and earlier secondary school study, possess more homogeneity than pupils at large, and therefore afford clues to promising methods of grouping individuals, either for specialized courses or for particular projects within the general course. Studies in which such elements as general intelligence and extent of preparation in mathematics are controlled are necessary in order to draw conclusions concerning the relative importance of these factors on success in college physics. It is primarily to the results for individual students, however, that attention must be directed if the maximum benefit is to be derived from such testing. Teaching is a highly personal relationship, and prerequisite to every effort to improve the standing of a particular class must be an appreciation of the potentialities of each of its individual members.

In conclusion we offer thanks to each department and teacher that have collaborated in this program. Without the generous and intelligent support that physicists have given through their use and criticism of these examinations, the committee could not, of course, carry on this project. Prime credit for whatever measure of success the program has attained, in serving as a partial basis for the evaluation of physics instruction and as a noteworthy example to college teachers in other fields, is due to members of the Association. In this cooperative venture they are in the vanguard of those who conceive of education as an orderly, measurable process that develops the individual to his fullest capacity and at the same time enables a science or a profession to take advantage of the best talent available.

The Committee also wishes to acknowledge the assistance rendered by the staff of the Cooperative Test Service, particularly by Dr. Ruth E. Eckert, Research Advisor, in the preparation of this report.

The Committee on Tests of the American Association of Physics Teachers

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Colloquium for College Physicists at the University of Iowa

A COLLOQUIUM for college physicists will be held at the University of Iowa, Iowa City, on June 16, 17, and 18. The program will include general lectures on electron emission, on the physical basis of valence, and on physico-biologic phenomena; several demonstration lectures; and round-table discussions at luncheon and dinner meetings.

Laboratory and Demonstration Experiments on the Law of Radioactive Decay and the Determination of the Disintegration Constant of Thoron

K. T. Bainbridge and J. C. Street
Department of Physics, Harvard University, Cambridge, Massachusetts

A STUDY of the disintegration of thoron is one of a series of laboratory experiments included in an intermediate course on X-Rays and Nuclear Physics. Of the three variations of the thoron experiment described, the first two are regularly used in course work, as all of the manipulations and measurements can be made by the students themselves. Any one instrument furnishes an interesting demonstration of radioactive decay and permits an evaluation of the half-period of thoron.

Thoron was chosen as the radioactive material for the following reasons:

1. It has a convenient half-period of decay T equal to 54.5 sec, corresponding to a disintegration constant $\lambda = 1.27 \times 10^{-2}$ sec.$^{-1}$.

2. The immediate product of disintegration, Th A, $T = 0.145$ sec., has a very short life compared to thoron and so does not introduce any error in the determination of the disintegration constant of thoron.[1]

3. The succeeding product of disintegration, Th B, has a long period, $T = 10.6$ hr., and its daughter elements have short periods, so that the residual ionization in the chamber is limited to a very small value compared to the initial ionization of the thoron.[2] The experiment may be repeated several times before the residual ionization need be taken into account.

4. Finally, an ounce[3] of thorium oxide is sufficient for 3 or 4 instruments and the small activity of the radioactive material involved does not introduce any risk to the students or instructor.

The ionization chamber and bottle containing thorium oxide or hydroxide form a closed system. As shown in Fig. 1 the thoron is pumped by an aspirator bulb into the ionization chamber through a drying tube containing "Hydralo."

A suitable thoron source is thorium hydroxide precipitated by adding dilute sodium hydroxide to a solution of thorium nitrate. The thorium hydroxide should be washed in a filter until all excess sodium hydroxide has been removed. The thorium emanation diffuses out very rapidly from the moist hydroxide.

1. Schonland Electroscope

Figures 1 and 2 show the simpler of the three types of apparatus. The ionization chamber may be any conducting container with close fitting ends. In this case stock brass tubing was used. A length of iron wire supported from a cast sulphur insulator is the collecting electrode.

The electroscope, a modification of the Schonland type,[4] consists of a vane of mica, aluminized on one side, supported from a brass block by two gold leaf hinges $\frac{1}{4}$ to $\frac{1}{2}$ mm wide with a free length of 1 to 2 mm. The hinges are attached by a minute drop of Aquadag.[5] The mica vane is generally somewhat distorted when the Aquadag dries but two out of three vanes have sufficient plane area left to give a good reflection of the light beam used to register the deflection of the

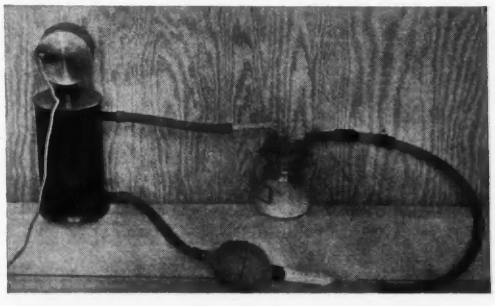

Fig. 1. Schonland electroscope, ionization chamber, thorium oxide reservoir, aspirator bulb and drying tube.

[1] The thorium A reaches its maximum amount at $t = [1/(\lambda_{Th\ A} - \lambda_{Tn})] \log_e (\lambda_{Th\ A}/\lambda_{Tn}) = 1.73$ sec. after the thoron has been introduced into the ionization chamber. Thereafter the thorium A is in transient equilibrium with the thoron and decays with the period of thoron [Harnwell and Livingood, *Experimental Atomic Physics* (McGraw-Hill, 1933), p. 377].

[2] If the ionization of the thoron and thorium A equals I_0 a few seconds after the introduction of the thoron, then the maximum value of the residual ionization from Th CC′ is approximately 0.1 percent of I_0 at $t \approx 25$ min.

[3] Costs $1 at Eimer and Amend, New York City.

[4] B. F. J. Schonland, Proc. Camb. Phil. Soc. **25**, 340 (1929).

[5] Colloidal graphite, Acheson Graphite Co., Port Huron, N. Y.

vane. The mica vanes, 3–4 mm wide and 4–5 mm long, are cut with a razor blade from aluminized strips of mica of the same width as the vane.[6] The proper thickness of the mica corresponds to a weight of 2 mg cm^{-2}.

The electroscope vane is charged to 250 to 350 v by a fine wire which may be rotated into contact with the vane support and collecting electrode. A vane of the dimensions given is slightly underdamped and has a very short period of $\sim$0.2 sec. The voltage response of the electrometer is very closely linear over a range of 10 cm deflection of the light spot at a scale distance of 100 cm.

Figure 3 shows a typical semilog plot of the ionization current *vs.* time, yielding a value of 54 sec. for the half-period of decay. Readings of

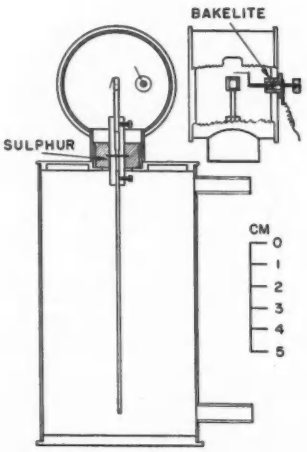

FIG. 2. Scale drawing of Schonland electroscope.

TABLE I. *Schonland electroscope.*

MEASURING PERIOD (SEC.)	DEFLECTION (MM)	i or Cdv/dt (10^{-2} V SEC.$^{-1}$)	MIDPOINT OF PERIOD (SEC.)
0–10	81	375 C	5
20–30	67	299	25
40–50	53	226	45
60–70	40	165	65
80–90	36	148	85
100–130	64.5	96	115
140–170	42.5	59	155
180–210	24.5	33	195
220–280	26.5	18	250
290–350	16.0	11	320

[6] Strips of aluminized mica may be obtained for $1 from Evaporated Metal Films Corp., Ithaca, N. Y.

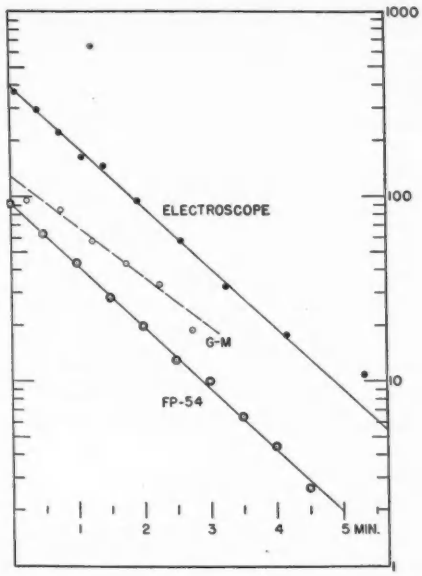

FIG. 3. Semi-logarithmic plot of ionization current *vs* time. Electroscope graph ordinates: 1 unit = $C\times10^{-2}$ v·sec.$^{-1}$, where C is the capacitance of the ion collecting system. Geiger-Mueller graph ordinates: 1 unit = one-quarter the number of counts per 30-sec. period. FP-54 graph ordinates: 1 unit = 10^{-13} amp.

the ionization current, proportional to the number of atoms disintegrating per second or to the number of atoms present, are taken at the end of 10-sec. periods, with 10 sec. between readings to allow for charging the electrometer and preparing for the next reading. Generally three students cooperate in making the readings. One acts as timekeeper, releases the charging wire at the beginning of a 10-sec. period, and indicates when a second student should read the deflection at the end of the period. A third student records and plots the data.

The ionization current i is plotted as a function of the time, the midpoint of a current-measuring period being used for t. It can be shown that no error is introduced into the determination of the half-period by the assumption that the average current corresponds to the current at the midpoint of the time interval, so long as the periods all have the same duration. It is necessary, however, to lengthen the current-measuring period after the thoron has decayed for 1.5 to 2 min. because the deflections over a

10-sec. period become too small to be read accurately. The first 5 or 6 readings should therefore be given greater weight than succeeding readings.

Table I contains sample data for the electroscope graph in Fig. 3.

2. Vacuum Tube Electrometer

An FP-54 amplifier,[7] or a more rugged and less sensitive equivalent,[8] connected to an ionization chamber[9] allows a quantitative measurement of the decay of thoron. The actual ionization current can be measured easily with the vacuum tube electrometer and from this the number of atoms disintegrating per second and the total number of atoms present initially, N_0, can be calculated if λ and the ionization produced by a single disintegrating atom are known. The α-particles from thoron produce very nearly 2×10^5 ion pairs before they are completely stopped in air. In addition, an approximately equal amount of ionization comes from the α-particles of Th A. As Th A has a half-life of only 0.145 sec., its atoms disintegrate nearly as rapidly as they are formed from the parent thoron. Consequently 4×10^5 ion pairs is taken as the amount of ionization produced in the disintegration of each atom of thoron. The simplifying assumption is made that all α-particles have their full range in the chamber.

The quantitative measurements illustrate for the student in a very striking manner the tremendous sensitivity of electrical methods in the measurement of radioactive substances. An initial ion current of 7.8×10^{-12} amp. corresponds to 122 atoms of thoron disintegrating per second. This corresponds to about 9500 atoms, or 3.6×10^{-18} g, of thoron initially present. The calculations required to secure these figures show that the "activity" and ease of detection of a radioactive element are a function of the decay constant, the number of atoms present, and the ionization produced per disintegration rather than simply the amount of an element present.

As a lecture demonstration the exponential decay of a radioactive substance can be shown by plotting the current readings taken at 20-sec. intervals over a period of 3 to 5 min. A "semi-logarithmic" graph of the current *vs.* time allows the half-period of decay to be evaluated immediately from the linear relation in these coordinates. The time required for the current to decrease to 1/8, 1/16, or 1/32 being equal to $3T$, $4T$, or $5T$ respectively. A typical graph is shown in Fig. 3.

3. Geiger-Mueller Tube

Figure 4 illustrates the third type of apparatus used for the measurement and demonstration of the decay of thoron. A small Geiger-Mueller counter with a cathode 1.5 cm in diameter and 2 cm long, and a 0.003-in. tungsten wire anode, is arranged so that it can be completely evacuated. Attached to the counter is a small reservoir which, in the case of the apparatus illustrated, contains about 0.5 g of anhydrous thorium oxide in air at 20 cm of mercury pressure. Glass wool is placed above the oxide to prevent its transport

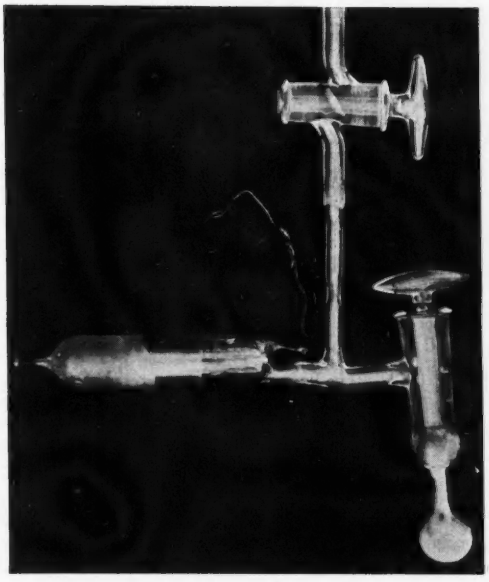

Fig. 4. G-M counter with thoron reservoir attached.

[7] L. A. DuBridge and H. Brown, R. S. I. **4**, 532 (1933); G. P. Harnwell, Am. Phys. Teacher **3**, 82 (1935).

[8] R. D. Huntoon, R.S.I. **6**, 322 (1935).

[9] The ionization chamber used with the Schonland electroscope will not work satisfactorily with a vacuum tube electrometer. A grounded guard ring is essential and the collecting electrode in the chamber must not be able to "see" the insulator.

into the counter. When the stopcock is opened the air mixed with thoron enters the counter and the final pressure in the G-M tube is 7 cm, the correct pressure for this counter. The counts, initially about 1400 per min., are registered and the impulses from the amplifier also are fed to a loud speaker. The rapid decrease in the number of audible impulses makes an interesting demonstration of radioactive decay. The number of registered counts in 30-sec. periods may be plotted to illustrate the decay of thoron as shown in Fig. 3. The original data have been plotted without correcting for the decreased efficiency of the counting circuit at high counting rates. The use of the Neher-Harper circuit[10] would eliminate the need for correcting the counting data.

The large statistical fluctuations inherent in this method prevent an accurate measurement of λ from a single experiment.

[10] H. V. Neher and W. W. Harper, Phys. Rev. **49**, 940 (1936).

Teaching Aids

Booklets and Catalogs

Electric Cleaners. *The Hoover Co.* (Home Economics Dept., North Canton, O.), gratis.

4 Lectures on Electric Cleaners, 28 p., 21×28 cm. Good discussions of the construction of various types of electric cleaners, and of nozzle suction, bag pressure, carpet structure, chemical properties of carpet dirt, and carpet wear.

A Laboratory Manual on Electric Cleaners. 27 p., 12 fig., 21×28 cm. Laboratory lessons for use with the lectures presented in the preceding booklet.

Chapters on Light Recommended for Inclusion in Physics Textbooks. Ed. 4. 56 p., 57 fig., 15×22 cm. *Illuminating Engineering Soc.* (51 Madison Ave., New York), paper cover, 25 cts. In 1923 a survey of secondary schools physics textbooks was made for the Illuminating Engineering Society to obtain information regarding the amount and character of the material therein on those subjects of light which deal with its principles, its measurements and control, and the application of modern illumination. The first edition of the present booklet was then prepared to provide additional or substitute subject matter and experiments for use in connection with the textbooks. The 6 chapters and 15 experiments in the booklet deal with light and vision, modern illuminants, units of light measurement, photometry, principles of light control, and adaptation of light to daily needs.

40 Years of Kliegl Lighting. Catalog No. 40. 96 p., 22×28 cm. *Kliegl Bros.* (321 W. 50th St., New York), gratis. A catalog of equipment for theatrical, decorative, and spectacular lighting, with many photographs of actual installations.

Household Refrigerator Service Manual. 60 p., 13 fig., 21×27 cm. *Copeland Refrigeration Corp.* (Holden Ave. at Lincoln, Detroit, Mich.), gratis. Gives the general principles of refrigeration and describes the operation, installation, and servicing of Copeland mechanical refrigerators. Good diagrams.

A Survey on the Use of Metric Measures. J. T. Johnson Department of Mathematics, Chicago Normal College. 5 p., 15×23 cm. *Metric Assoc.* (Pottsville, Pa.), gratis. A tabulation of the answers to a questionary on the metric system sent to 391 manufacturers and 349 engineers, physicians, educators, etc. In order to get a random sampling, the questionary was not sent to physicists or other groups already known to be in favor of the metric system. The pedagogic implications of the results of the questionary are discussed.

Automatic Heating and Air Conditioning. *Minneapolis—Honeywell Regulator Co.* (Minneapolis, Minn.), gratis. Three booklets, entitled "This Thing Called Automatic Heating and Air Conditioning," "And Then. . . . We Turn On The Heat," and "Condensed Catalog & Price List," which discuss automatic heating, ventilating, and air conditioning systems in general, and describe various indicating, recording and controlling instruments.

Motion Picture Films

Water Power. 16 or 35 mm, sound film or silent, 11 min. *Erpi Picture Consultants* (New York), outright sale only. Traces the development of water power, pictures the transformations of energy involved, and concludes with a world-wide survey of potential water power.

Catalysis. 16 or 35 mm, sound film or silent, 11 min. *Erpi Picture Consultants* (New York), outright sale only. Produced in collaboration with the University of Chicago, this film pictures concentration and activation by absorption, intermediate compounds in a homogeneous mixture, chain reactions, poisoning of catalysts, negative catalysts, etc.

Know Your Coal. 16 or 35 mm, sound film, 22 min. *U. S. Dept. of the Interior* (Motion Picture Div., Washington), loaned gratis. Detailed testing of bituminous coal, for the education of those who handle and use it.

NOTES ON APPARATUS AND DEMONSTRATIONS

A Portable Laue Spot Camera

A PORTABLE Laue spot camera developed with the idea of simplicity of operation so that it might be used by undergraduates in an advanced general experimental physics course is shown in Fig. 1. Essentially the apparatus is merely a brass tube 16 cm long and 2.5 cm in diameter. In each end of the tube there is a lead plug 2 cm long with an opening made by a No. 57 drill. A hinged wooden frame, $6\frac{1}{2}\times4\frac{3}{4}$ in., holds the intensifying screen and an x-ray film, $3\frac{1}{2}\times5$ in. (5×7, cut in two). The tube and plate holder are mounted on the base of a discarded Pascal's vases demonstration outfit. The crystal is fixed with soft wax at the surface of the second pinhole, the one nearer the film holder. The usual arrangement[1, 2] is to collimate the x-ray beam by using 2 pinholes, then fix the crystal over a third pinhole which itself has to be aligned with the collimating pinholes, although Wyckoff[3] mentions using 2 or more pinholes.

The circular lead "collar" at about the middle of the brass tube is used to shield the x-rays coming from the target since the brass tube is put into a square hole in the lead box holding the x-ray tube; the larger square collar at the crystal end is to prevent fogging of the film by possible scattered x-rays. The lead button seen mounted so as to cover the central position of the film is to prevent halation produced by the direct beam.

Figure 2 shows a photograph obtained recently with a $CaCO_3$ crystal with no adjustments necessary after the "camera" had been out of use for more than six months, and in the meantime had been moved around considerably. No attempt was made to find a perfect crystal; the one used was obtained by cleavage from a larger piece, and measured about 3×4 mm and 1 mm thick. The x-ray tube was a Coolidge water cooled type with a tungsten target operated at about 40 kv and 15 ma, full-wave rectification. The exposure time of about 4 hr. was a great deal more than necessary but was used in order to produce dark spots that would reproduce easily. An exposure of 1 hr. gives a sufficient number of spots for student measurement. The same number of spots were obtained with a Coolidge water cooled molybdenum tube in about twice the time when operated at 25 kv and 15 ma.

FIG. 2. Laue spot photograph for $CaCO_3$, incident beam approximately perpendicular to a cleavage face.

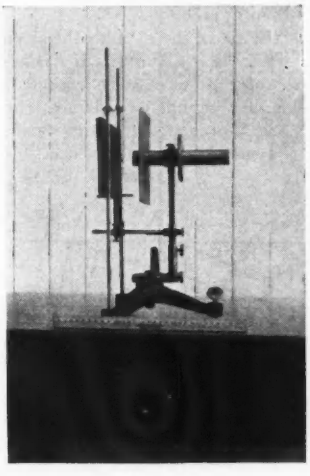

FIG. 1. The Laue spot camera.

It is hoped that the compactness and simplicity of the "camera," together with its portability and the results obtained with the elimination of the third pinhole, will justify this description of an apparatus for which the author claims very little originality.

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[1] Harnwell and Livingood, *Experimental Atomic Physics*, p. 335.
[2] Weber, McGee, and Gerhard, Am. Phys. Teacher 5, 279 (1937).
[3] E. Wyckoff, *The Structure of Crystals* (Ed. 2), p. 124.

Effect of Area of Contact on the Tractive Effort of a Magnet

THE force between a magnet and its armature is shown in the average textbook on electricity and magnetism to be $F=B^2A/\mu 8\pi$, where B is the flux density, A the area of contact, and μ the permeability of the gap between the magnet and the armature. The equation may be written in the form

$$F=\frac{\phi^2}{\mu 8\pi A} \tag{1}$$

and, if the flux remains constant, it indicates that the attractive force varies inversely with the area. This fact is well known and although mentioned or derived in most texts, leaves the student unconvinced, and still unwilling to believe that the force between a magnet and its armature becomes greater when the contact area is reduced.

It is of course not difficult to set up an electromagnet and, with armatures of different areas, to measure the tractive effort when the current is adjusted to insure a constant flux at all times. It is also possible, however, to secure with permanent magnets convincing evidence concerning the effect of contact area even though the flux may not remain constant. For example, in suspending tacks, one from another, under the influence of a magnet it is usually possible to pick up one more, point to point, when it is not possible to hold an additional tack by its head. Also, if the armature of a permanent U-magnet be placed on the poles in such a fashion as to contact a small area of one pole while completely covering the other, less force is needed to lift the end of the armature from the completely covered pole.

More specifically, the following simple demonstrations have been found convincing. Two armatures about 1 mm thick are made for an ordinary U-magnet, one just long enough to extend over about 1 mm of each pole face, and the other long enough to cover both pole faces. The armature and the pole faces of the magnet are sandpapered fairly flat. It may be necessary to weaken the magnet by reversing it a few times near a small electromagnet so that the magnet will hold its own weight when held by the short armature placed flat against the pole faces but cannot be lifted by the longer armature also held flat. Evidently the tractive effort is greater with the smaller area of contact. The total flux is not constant in these two instances but it is smaller for the case of the small contact area, which nevertheless furnishes the greater force.

Moreover, if now the longer armature is held edgewise on the pole faces, the magnet can be lifted, but when the armature is rotated to the flat position, the magnet falls. This should leave no doubt in the student's mind that the force is greater with the smaller contact area.

These experiments may be repeated with a thin sheet of paper between the magnet and the armature to eliminate any question of the influence of the fit of the surface.

SIMON SONKIN

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Wave-Length Determined from the Chords of Newton's Rings

THE simplest device, and the one most frequently resorted to, for demonstrating interference in thin films in an elementary physics laboratory is the Newton's rings arrangement. Its usefulness from a quantitative point of view, especially in determining wave-lengths of light, can perhaps be increased if the facts of the following discussion are presented to the student.

The difference between the squares of the *chords* C of two concentric Newton rings is equal to the difference between the squares of the *diameters* D of the same rings. This statement can be proved by applications of the Pythagorean theorem to the right triangles indicated in Fig. 1:

$$C_n^2=D_n^2-4h^2, \tag{1}$$

hence

$$C_n^2-C_m^2=D_n^2-D_m^2. \tag{2}$$

Here n and m designate the nth and mth rings, and h represents the separation of the common line of chords and the common line of diameters.

A realization of the equivalence expressed by Eq. (2) should convince the student that it is not necessary to attempt to make the cross hair intersection of his microscope eyepiece follow diameters. It should also convince him that, provided he has made and handled a set of measurements carefully, any appreciable error in wave-length determination probably arises only from an uncertainty in the value of the radius of curvature r of the spherical surface used in producing the rings.

The easiest way to handle the data is to plot the squares of the chords, or diameters, against the integral numbers of the rings. That the graph should be a straight line is shown by an extension of the usual sagitta-formula method of obtaining a relationship between D_n and n. This method yields the formula for bright rings,

$$C_n^2=2r\lambda(2n-1-k)-4h^2, \tag{3}$$

where k is a fractional constant which enters whenever the film thickness at "the point of contact" is not equal to a multiple of $\lambda/2$. If $h=0$, then $C_n=D_n$.

Either with or without the aid of the calculus the slope of the graph may be shown to be equal to $4r\lambda$. If r is accurately known, a good value of λ may be expected. Even if an accurate value of λ cannot be obtained, the graphical representation still affords an interesting verification of the fundamental assumption of interference.

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JOSEPH W. ELLIS

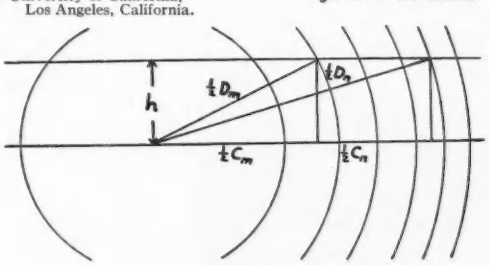

FIG. 1. Wave-length from chords of Newton's rings.

An Example of the Relativity Change of Mass with Speed

THE increase in mass of a particle moving with a speed approaching that of light, which is demanded by the theory of relativity, is commonplace in modern physics, but it rarely manifests itself in a striking visual manner. Fig. 1 is a cloud chamber photograph of the collision of a very high speed electron with an electron at rest, in which the change in mass is rather obvious. Such photographs of collisions of this kind at very high speeds are rather rare, this being the only one obtained in some 10,000 photographs. The paths of the electrons are curved, because of a magnetic field which was applied in a direction perpendicular to the plane of the paper.

In ordinary low speed collisions of one moving particle with an identical particle at rest (such as billiard balls) the angle between the directions of flight of the two particles after collision is always 90°. Although the electron collision shown in Fig. 1 is just such a collision (except at high speed) the angle of separation is only 41.5°. This may be interpreted as meaning that the mass of the moving particle before collision was almost as great as the sum of the masses of the two particles after collision. The measured angles and curvatures are consistent with the predicted relativity change of mass, namely $m=m_0/(1-\beta^2)^{\frac{1}{2}}$, to within a few percent, as anyone can check from the following measurements:

Strength of magnetic field, 1425 oersted;

Radius of curvature of primary path, 15 cm;

Radii of curvature of paths after collision, 5 and 10.5 cm;

Angle between 5-cm and primary paths, 28°;

Angle between 10.5-cm and primary paths, 13.5°;

Speeds (calculated), 0.9969, 0.9936 and 0.9728 times the speed of light, for the 15-, 10.5- and 5-cm paths, respectively.

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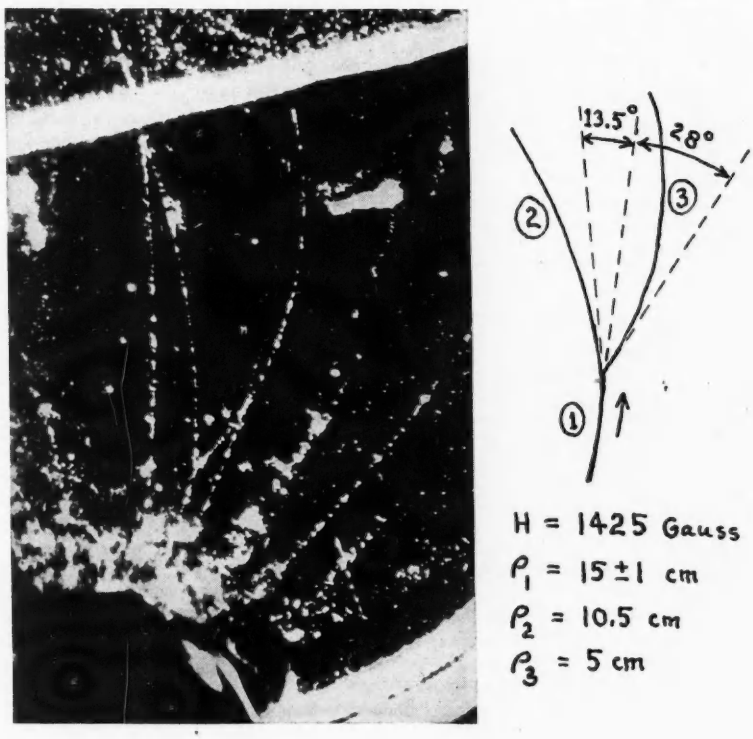

FIG. 1. Collision of a high speed electron with an electron at rest.

Among My Souvenirs

AMONG various items of interest for which I am indebted to my students, are the following, which may be new to some readers.

One student had been renewing the window-lights in the curtains of an old automobile with transparent celluloid and observed how readily the celluloid developed an electrical charge. He nailed a large sheet of it over a frame, which he brought to me, and called my attention to the fact that, if bits of paper are clinging to the celluloid and the hand is brought up under the *opposite* side, the paper bits will jump about from place to place—like fleas.

A night student had dismantled a desk lamp which has a flexible support consisting of an armored brass cable with about 6 spirals per inch. He removed the wire from the armor, and while blowing out the fragments of insulation, discovered what I have named an "Ethiopian bagpipe." By changing the pressure, one can blow notes of almost infinite variety.

One of my least-promising boys tried to tell me of an experience he had at home while combing his hair. I had him demonstrate it before the class. After a few preliminary strokes of the hair with his pocket comb, he turned on a slender stream of water from the faucet. Holding the comb as though he would wet it, he showed that the stream of water would curve through an angle of 90°.

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Washington, D. C.

RICHARD L. FELDMAN

DISCUSSION AND CORRESPONDENCE

Concerning the New Book on Demonstration Experiments

MANY of those who have been so patiently awaiting the publication of the A. A. P. T. book on *Demonstration Experiments in Physics* will be interested to know that the manuscript is now in the hands of the publisher, the McGraw-Hill Book Company, and that the prospects are good for its publication by June 1. We wish to take this opportunity to thank the many members of the Association who have cooperated in this undertaking, and to invite their continued interest in it. After the book appears, there will doubtless be numerous points where members can suggest additional experiments. We will welcome this information and any suggestions for improvements in the experiments already described.

The book will comprise 500–600 pages, with more than 400 illustrations and line drawings. There are nearly 1200 individual experiments described, covering the gamut of physical principles and ranging in grade from the very simple to the comparatively difficult. We have tried to include sufficient experiments requiring only modest equipment so that *every* teacher of physics in either college or secondary school will find the book valuable to him; and we have likewise included enough advanced material to keep even the best-equipped department busy for some time to come.

Advance order for the book may be made on a postal card addressed to me. The book will be billed at list price less the professional discount, at an actual cost of somewhat under five dollars.

RICHARD M. SUTTON

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Center of Gravity and Center of Mass

THE terms *center of gravity* and *center of mass* are usually used almost interchangeably in elementary and intermediate mechanics texts—yet such loose usage overlooks a distinction in principle of some importance. Because of the large number of texts that have appeared recently in which the conceptual difference between center of mass and center of gravity is not stressed or even pointed out, the writers think it desirable to focus attention on the distinction.

The term *center of mass* can be given an essentially geometrical definition,

$$r_{c.m.} = \frac{\int r\,dm}{\int dm},$$

which is always used in actual center of mass calculations.

The situation is not as clear-cut when we deal with *center of gravity*; at least three conceptually different definitions of center of gravity can be given. First, it can be defined, and usually is, as the point (not necessarily inside the body, as in the case of a hoop) such that when a body on the earth's surface is supported from that point it will remain in equilibrium regardless of its orientation. This definition assumes uniformity of the earth's gravitational field near its surface; in all cases the center of gravity so defined is identical with the center of mass.

Second, center of gravity of a body can be defined as that point at which a single force must be applied to maintain the body in equilibrium when the body is in a non-uniform gravitational field. For any assigned orientation of the body, such a point exists, at least for fields in which couples may not arise; but it is certainly not truly that for most bodies such a point exists independently of orientation. For various orientations the intersections of the lines of action of the single equilibrating forces cut out a region in space which converges to a point as the field approaches uniformity.

Finally, center of gravity can be defined as center of gravitational attraction; that is, the single point at which all the mass of a body can be concentrated without changing the gravitational field of the original object. Again such a definition implies that only certain very special bodies have centers of gravity—namely, the centrobaric bodies,[1] such as homogeneous spheres, and bodies obtained by inversion of such spheres.

Since our first definition of center of gravity always leads to a coincidence of the centers of mass and of gravity, and since most objects do not have centers of gravity as defined in the other two senses, it would make for economy and accuracy of expression if the term center of mass were used exclusively in examples in which the earth's field is considered uniform. According to this usage the weight of an object would act at its center of mass. The term center of gravity could then be reserved for situations (astronomical, electrostatic etc.) in which non-uniform fields are considered. Whether the second or third definition of center of gravity is appropriate would depend on the particular problem; but in any case stress should always be placed on the fact that centers of gravity so defined do not exist for most bodies.

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ALVIN M. WEINBERG

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[1] W. D. MacMillan, *The Theory of the Potential* (McGraw-Hill), p. 212.

RECENT PUBLICATIONS

General Physics Textbooks*

A Textbook of Physics. Louis Bevier Spinney, professor of physics, Iowa State College. Ed. 5. 733 p., 481 fig., 25 tables, 14×21 cm. *Macmillan*, $3.75. In this new edition the chapters on thermal expansion and on electromagnetic waves have been revised, the treatments of radiation and of atomic structure have been extended, and a new chapter on electron tubes has been added. Other alterations that clarify and modernize the treatment have been made. Most of the problems are new and 50 new figures have been added.

Foundations of College Physics. Samuel Robinson Williams, professor of physics, Amherst College. 640 p., 534 fig., 33 tables, 15×23 cm. *Ginn*, $4. The author of this text for a standard first-year course has sought to emphasize both the purely physical and the mathematical, analytic approaches to fundamental phenomena, and yet to balance the treatment with good material drawn from the historical and cultural aspects of the science. Many photographs, as well as diagrams, are employed. Emphasis is placed on precise statements of concepts and units. To avoid confusing the student with a multiplicity of units, the c.g.s. system is used almost exclusively.

Kimball's College Physics. Revised by Peter I. Wold, professor of physics, Union College. Ed. 5. 741 p., 585 fig., 48 tables, 15×21 cm. *Holt*, $3.75. New material of importance has been added to this edition and at the same time the volume has been condensed about 10 percent. The treatment of sound has been modernized. The sections on heat have been rearranged, with the material on the Carnot theorem now appearing in the body of the text. Electricity, especially electrostatics, has been largely rewritten and more space has been given to alternating current phenomena. There are some 200 new figures.

Physics for Technical Students: Vol. I, Mechanics and Heat; Vol. II, Sound, Electricity, Magnetism, Light. William Ballantyne Anderson, professor of physics, Oregon State College. Ed. 3. 387 and 445 p., 226 and 308 fig., 25 and 19 tables, 15×23 cm. *McGraw-Hill*, $2.50 per volume. The practical side of physics is emphasized in this text for students of the sciences, agriculture, and engineering. The two volumes of the present edition contain 183 new figures and 750 problems that are mostly new or revised. In Vol. II light follows electricity instead of preceding it as heretofore.

Elementary College Physics. Norman E. Gilbert, professor of physics, and Leslie F. Murch, professor of physics, Dartmouth College. 459 p., 334 fig., 16 tables, 15×21 cm. *Harcourt, Brace*, $3.50. A text for a brief one-year course for nonphysics and nonengineering majors and for students who wish to meet the minimum requirements for medical schools. The authors have tried to make the treatment of fundamental principles complete, the brevity being obtained by omitting some of the more advanced material usually included in each chapter of the standard texts. The trigonometry employed is explained as it is introduced.

Physics. Erich Hausmann, professor of physics, and Edgar P. Slack, assistant professor of physics, Polytechnic Institute of Brooklyn. 784 p., 471 fig., 59 tables, 14×21 cm. *Van Nostrand*, $4. This text for a one- or two-year course covering the usual divisions of general physics aims particularly to present the essentials of the subject to students who major in science, technology, or engineering. A third of the book is devoted to mechanics, the discussion there being relatively detailed, and the steps in the mathematical formulations and worked examples complete. In the remaining divisions, the treatment is made gradually more concise, in keeping with the increasing comprehension of the maturing student. Considerable emphasis is placed on the proper use of units. Calculus is not employed.

College Physics. John A. Eldridge, professor of physics, University of Iowa. 626 p., 407 fig., 52 tables, 13×21 cm. *Wiley*, $3.75. The author has written this book with the belief that physics is interesting and useful for every student, and that it has something very real to contribute to present-day education. Although the book is intended to appeal to the student with only a general interest in the subject, an attempt is made to provide at the same time a solid foundation for the student with a professional interest in the science. Much material of the cultural type therefore appears in the main part of the text while topics of more specialized interest are marked with asterisks. Many incidental or qualifying remarks appear in secondary type or in footnotes. Both qualitative and quantitative questions are provided.

Physics for Students of Applied Science. J. Edmond Shrader, professor of physics, Drexel Institute of Tech-

* In forthcoming issues a new method of reviewing elementary and intermediate textbooks will be tried. A factual, uncritical notice, similar to those appearing in this issue, will be published as soon as the book appears on the market. Then, after the book has received actual trial in classrooms, a committee consisting of several physicists who have taught the book will be invited to prepare a critical review. This policy with regard to textbook reviewing is not employed elsewhere, in any field, so far as we know; but it appears to have desirable features that warrant giving it a trial. Both teachers and publishers rather generally agree that critical pre-reviews of textbooks are seldom very useful or satisfactory, and this largely because even the most experienced teacher finds it difficult to judge a textbook correctly until he has used it with students. We hope that out of this proposed series of post-reviews prepared by committees there may develop some broad and constructive ideas and criticisms that will be of value to authors in preparing and revising texts, and to teachers in selecting the books which they will use in their courses.—The Editor.

nology. 647 p., 583 fig., 20 tables, 15×23 cm. *McGraw-Hill*, $4. A text intended primarily for students of engineering. Fundamentals are stressed, modern developments being touched on lightly and only for the purpose of giving the student a glimpse of the material that should be treated adequately in a second-year course. Calculus is used sparingly in the latter parts of the book. Electricity appears immediately after heat because it is needed for the subjects that follow and also because this fits into the sequence of study of electrical engineering. Two complete sets of problems, one with answers, are provided for each major division of the book.

First Year Laboratory Manuals

Elementary College Physics, Laboratory Manual. Norman E. Gilbert, professor of physics, and Leslie F. Murch, professor of physics, Dartmouth College. 210 p., 71 fig., 14×16 cm. *Harcourt, Brace*, $1.90. Fifty-eight experiments, most of them requiring apparatus of a relatively simple character.

A Manual of Physical Measurements. Anthony Zeleny, professor of physics, and Henry A. Erikson, professor of physics, University of Minnesota. 296 p., 147 fig., 43 tables, 13×20 cm. *McGraw-Hill*, $2.25. Relatively brief directions for 89 experiments given in the courses in general physics and 35 experiments given in a one-quarter junior course in electrical measurements at the University of Minnesota.

Experimental Physics. Samuel Robinson Williams, professor of physics, Amherst College. 158 p., 115 fig., 21 tables, 19×28 cm. *Ginn*, paper, $1. Forty-two experiments for a standard course. The first three experiments are written so that they may be either carried out by the student or performed by the instructor as a demonstration of the way in which laboratory work should be done. The pages are perforated and punched, and include data sheets and graph paper for the student's reports.

Intermediate Textbooks*

Light—Principles and Experiments. George S. Monk, assistant professor of physics, University of Chicago. 488 p., 262 fig., 23 tables, 15×22 cm. *McGraw-Hill*, $5. A textbook and laboratory manual on geometrical and physical optics, for students who have had general physics and elementary calculus. The first 88 pages are devoted to geometrical optics, a subject which the author believes is only too often not a familiar one to students of the sciences who will later use optical instruments whose principles they should understand. The remaining 229 pages of the text proper deal with classical physical optics, the more recent extensions of physical optics dealing with the origin of spectra, the interactions of light and matter, magneto- and electro-optics, and recent progress in colorimetry. Ninety-eight additional pages are devoted to 23 laboratory experiments designed to accompany the course. Answers for the problems are given.

Fundamentals of Physical Optics. Francis A. Jenkins, associate professor of physics, and Harvey E. White, associate professor of physics, University of California. 467 p., 273 fig., 14 tables, 15×22 cm. *McGraw-Hill*, $5. In this text for students who have had general physics and some elementary calculus, the authors have sought to emphasize physical explanations, and they believe that in wave optics this can be most successfully accomplished by the use of many accurate diagrams. Geometrical optics is not reviewed, since the knowledge of it gained in general physics is deemed ample for an understanding of the present treatment. A systematic discussion of the quantum theory is not included, on the grounds that it would require considerable space and would tend to destroy the unity of the treatment. The authors feel that there should be more general recognition of the point of view emphasized by quantum mechanics; namely, that the wave and particle properties of radiation are merely different complementary aspects of the same thing, and that one aspect will probably never be more important than the other. This leads to a logical way of separating the subject matter of physical optics into two sharply divided parts and makes it possible, and the authors believe desirable, to present wave optics and the quantum picture in separate courses. The 19 chapters of the book begin with the fundamentals of wave motion and then lead to interference, diffraction, speed of light, electromagnetic theory, light sources and spectra, absorption and scattering, dispersion, polarization, optical activity, reflection, and magneto- and electro-optics.

Advanced Textbooks and References

The Flow of Homogeneous Fluids Through Porous Media. M. Muskat, chief of physics division, Gulf Research & Development Co. 782 p., 284 fig., 21 tables, 15×23 cm. *McGraw-Hill*, $8. This important text and reference makes available for the first time a complete treatment of the flow of homogeneous fluids through porous mediums. Aside from single, brief chapters on *incompressible* liquids in three German books, no other summarized treatment of the subject, either elementary or advanced, exists in book form. The first 146 pages of the book give the experimental basis for the fundamental laws involved in the subject, the technic for determining the permeability of a porous medium, and the mathematical formulation of the empirical laws which form the starting points for the analysis in the remainder of the book. The next 303 pages treat a succession of problems of fluid flow in the steady state. Two final chapters deal with the nonsteady state flow of liquids and the flow of gases through porous mediums. The author points out that, while the problems treated are in many cases of interest only in the oil and gas industries, a considerable part of the discussion should be applicable also to hydrology, dam construction, and problems involving fluid flow through refractories and ceramic materials.

DIGEST OF PERIODICAL LITERATURE

Demonstrating Compounded Harmonic Vibrations

A projection apparatus for compounding harmonic vibrations. R. M. Archer; *J. Sci. Inst.* **14**, 408–10, Dec., 1937. Apparatus is described by which two or more simple vibratory motions may be combined optically with any desired amplitudes and phases, and both Lissajous' figures and the combinations of a wave with one or more of its harmonics may be demonstrated. Light from a point source after successive reflections from plane mirrors mounted to vibrate or rotate, is focused on a screen as usual, but the motion of the mirrors is controlled both as to phase and amplitude by intermittent currents obtained from a rotating interrupter.

Undergraduate Research

A proposal for cooperative junior research. W. P. Cortelyou and E. H. Cortelyou; *J. Chem. Ed.* **13**, 565, Dec., 1936. The research worker often has to spend precious hours in obtaining minor data missing in the literature because these data are needed before he can go on with his major problem. Even the most complete handbook has an appalling number of blanks in the tables devoted to such common properties as specific gravity, solubility, and melting and boiling points. Often the data given are useless. Furthermore, an examination of successive editions of the handbooks often reveals changes so marked as to undermine one's faith in most published data of this kind; indeed, it is commonly assumed that if any such data are to be put to a serious use, they must be determined anew for the occasion. Probable reasons for this unsatisfactory situation are that the determination of such minor data appears to be too simple or of too limited interest to justify its inclusion as even a part of a graduate thesis, and that the machinery for collecting such data as have been determined is inadequate.

Such problems could be turned over to undergraduate students, unreliability being guarded against by having each problem pursued by at least two students, independent of and unknown to each other. This could be made possible by the establishment of a central correlating committee, appointed by a national society, which would act as a national clearing house for problems and results. Research workers would be asked to suggest problems and the central committee would assign these to students asking for problems, in many cases to those working under the persons who made the original suggestions.

Obviously the publication of individual papers on each problem would be impracticable, but a summation of results accepted by the committee could be published in some journal, the names of the contributors being mentioned. As a further motivation to such research on the part of undergraduates, a certificate could be awarded to each student who contributes a result that proves to be valid by the test of independent checking. Those who doubt the importance an undergraduate would attach to such a certificate should remember that millions of adults toil over lodge rituals to obtain some such title as Exalted Night Hawk, that thousands of housewives devise recipes in the hope of winning certificates of approval from certain household magazines, and that many Boy Scouts work very hard for merit badges. Such nationally sponsored junior research should help those colleges that are dissatisfied with the results now obtained in undergraduate research.

Premedical Requirements

Premedical training. R. I. Grady and J. W. Chittum; *J. Chem, Ed.* **13**, 528–9, Nov., 1936. Because most medical schools have more applicants for admission than they can possibly accommodate, the student who wants to be

Table I. *Summary of replies.*

Subject	Sem. hrs.	Requiring	Recommending	Requiring or Recommending	Doubtful	Not Desiring
Biology:						
General	4	34	2	36*	1	1
Zoölogy	4	35	3	38*	0	0
Vertebrate anatomy	4	16	25	41*	0	0
Physiology	4	1	8	9	15	14
Vert. embryology	4	6	26	32*	5	2
Animal histology	4	0	12	12	11	13
Histological tech.	4	0	9	9	17	10
Genetics	4	3	25	28*	6	0
Chemistry:						
General inorganic	8	41	0	41*	0	0
Qualitative anal.	4	20	18	38*	1	0
Quantitative anal.	4	18	17	35*	4	0
Adv. Quant. anal.	4	0	11	11	16	1
Organic, 1st sem.	4	41	0	41*	0	0
Organic, 2nd sem.	4	31	7	38*	0	0
Food and nutrition	3–6	0	8	8	16	7
Physical	4–8	1	37	38*	3	0
Biochemistry	4	0	4	4	14	16
Economics	6	1	28	29*	2	1
English:						
Freshman literature	6	35	5	40*	0	0
General literature	6	9	25	34*	3	0
French, elementary	10	23	11	34*	3	1
2nd year	8	11	13	24*	4	1
German, elementary	10	27	11	38*	0	0
2nd year	8	14	14	28*	1	0
Greek	10	0	7	7	14	6
History, European	6	2	22	24*	8	0
American	6	0	22	22*	8	0
Latin:						
2 yrs. high school		4	2	6	0	0
4 yrs. high school		2	21	23*	4	0
Cicero and Livy	8	0	4	4	13	5
Math. Trigonometry	3	7	26	33*	2	0
Anal. Geometry	3	1	17	18	8	1
Philosophy	3	1	22	23*	6	1
Physics, general	8	41	0	41*	0	0
Adv. physics	4	0	14	14	11	2
Psychology	3	2	28	30*	3	1
Bible	4	0	7	7	17	3
Sociology	3	1	28	29*	4	0
Speech	3	0	23	23*	5	1

* Required or recommended by a majority (22 or more).

reasonably sure of being accepted somewhere must send in his application to several different medical schools. It therefore becomes necessary for him so to plan his course that it will fulfill the requirements for admission to any school. Since the deans of the medical schools are the only ones who have a broad vision in the matter based on experience, they are the only ones who can judge how the various medical students are aided or handicapped by the nature of their premedical training.

A questionary was therefore sent to the deans of all the Class A medical schools of the country with the request that they designate what courses they (1) require, (2) recommend, (3) are doubtful as to the value of, and (4) do not desire. Table I contains a summary of the 41 replies received. While this summary indicates the courses considered essential or desirable, the comments of the deans show that there is a flexibility which cannot be indicated in any summary. In some medical schools the tendency is to select a high class candidate even though he lacks some of the highly recommended courses. Some of the comments stressed the importance of a good background of general education, and mentioned the undesirability of including subjects such as physiology, biochemistry, etc., which are a part of the essential curriculum of medical schools and therefore represent duplications.

LORD RUTHERFORD

The Right Hon. Lord Rutherford, 1871–1937. A. S. EVE, J. CHADWICK, J. J. THOMSON, W. H. BRAGG, N. BOHR, F. SODDY, E. N. DA C. ANDRADE, AND F. E. SMITH; *Nature*, **140**, 746–54, Oct. 30, 1937. Ernest Rutherford was born in New Zealand on August 30, 1871. With C. T. R. Wilson, Townsend, and H. A. Wilson, he studied at Cavendish Laboratory, Cambridge, under Sir J. J. Thomson. In 1898 he became research professor of physics at McGill University, Montreal. There he and Frederick Soddy studied the relation between thorium and thorium X and put forth the bold theory of the spontaneous disintegration of radioactive elements. Rutherford's first book, *Radioactivity*, was written with "a breathless enthusiasm."

A great part of his life was spent in investigating the properties of α-particles. In 1904 Ramsay and Soddy definitely obtained the helium spectrum from aged radon, and five years later Rutherford and Royds collected the α-particles ejected from radon and proved spectroscopically that they were helium atoms. Otto Hahn worked with Rutherford for a time at McGill and discovered radioactinium. Rutherford's conception of the atom as a heavy, positively charged nucleus surrounded by a cloud of electrons in appropriate number was first announced at a meeting of the Manchester Literary and Philosophical Society. This nuclear theory was the culmination of his work on the α-particles and the finest of all his great contributions to physics. In 1919 Rutherford left Manchester and succeeded J. J. Thomson as Cavendish Professor of Experimental Physics at Cambridge.

J. J. Thomson says that Lord Rutherford's death on October 19, 1937, "just on the eve of his having in the high tension laboratory means of research far more powerful than those with which he had already obtained results of profound importance, is, I think, one of the greatest tragedies in the history of science."

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

20. Ph.D. Univ. of Minnesota; S.B., S.M., M.I.T.; 1 yr grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yrs teaching experience in universities, colleges and technical schools, including 10 yrs head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

21. M.S. Kansas State. Age 38, married, 2 children. Research, acoustics. Experienced in laboratory maintenance, design and construction of apparatus, and writing of manuals. Desires teaching or industrial laboratory employment.

22. Ph.D. Univ. of Illinois; A.B. Wabash College. Age 31, married, 2 children. Has taught 4 yrs in liberal arts college and 1 yr in large state university. Co-author, laboratory manual. Interested in college or university teaching, laboratory development, and research. Available, fall 1938.

23. M.S., B.S. Louisiana State Univ. Age 24, unmarried. 2 yrs teaching fellow, physics; 2 yrs practical engineering experience; 2 summers, seismic prospectings. Desires teaching or industrial laboratory position.

24. Ph.D. Age 32, married, no children. Experience: 4 yrs secondary school; 4 yrs instructor, state university; 3 yrs head of physics and mathematics, liberal arts college. Author, laboratory manual. Two research grants. Desires position in larger college or university.

25. Ph.D. Yale. Age 33, married, 2 children. Industrial research experience; 3 yrs instructor in small college. Interested in teaching in coeducational or mens liberal arts college. Available June 1938.

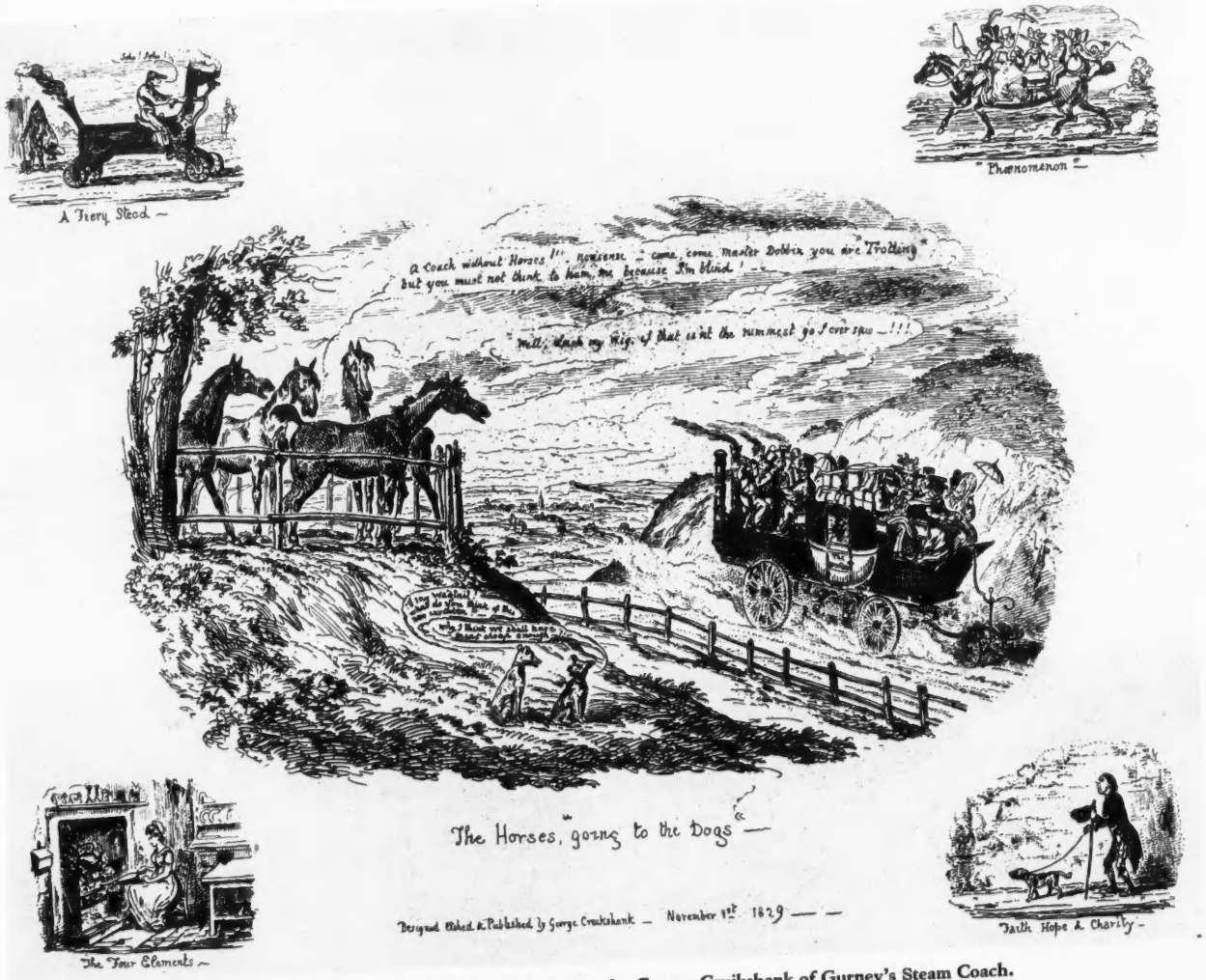
26. Ph.D., with long experience in an American college in China, wishes a college teaching position.

27. Ph.D., physics, Northwestern '35; A.B., engineering, Harvard. Age 42, married, 3 children. Experience: 1 yr., lt., artillery; 12 yrs. business and sales; 5 yrs. college teaching. Interested in undergraduate teaching, including astronomy.

28. B.S. in E.E., M.S., physics, Dr. Phil. Nat. from German univ. (Exchange fellow from U. S.) Age 32. 7 yrs. teaching experience in advanced courses and physics for engineers.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Any member of the American Association of Physics Teachers may register for this Appointment Service and have a "Position Wanted" announcement published without charge.


A Fiery Steed —
"Phenomenon" —
A Coach without Horses !!! nonsense — come, come master Dobbin you are "Trotting" but you must not think to Ham me because I'm blind ! —
well, thank my Wig, if that is'nt the rummest go I ever saw —!!!
The Horses, going to the Dogs —
Designed Etched & Published by George Cruikshank — November 1st 1829 — —
The Four Elements —
Faith Hope & Charity —

The First Journey by Automobile—A Caricature by George Cruikshank of Gurney's Steam Coach.

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REPRODUCTIONS OF PRINTS, DRAWINGS AND PAINTINGS OF INTEREST IN THE HISTORY OF PHYSICS

E. C. Watson

California Institute of Technology, Pasadena, California

1. The First Journey by Automobile

a Caricature

by

George Cruikshank of Gurney's Steam Coach

In historical studies good caricatures, such as those of George Cruikshank (1792–1878), are often of real value as well as of considerable interest. From them the student may learn what questions, ideas, events and incidents are occupying public attention, and judge of the popular reaction to them.

About 1830 great interest in steam carriages developed in England. This was due in large measure to the work of Sir Goldsworthy Gurney (1793–1875), whose steam coach, patented in 1827, is accurately portrayed in this rare and little known caricature. In 1829 the coach of Gurney accomplished, with a number of stops, the trip from London to Bath, the first journey of any length to be made by an automobile. The feat and something of the popular reaction to it is preserved for us in this amusing contemporary print.

Other caricatures of this kind, as well as serious prints of the steam coaches of Gurney, Church, Hancock and others, will appear later in this series of historical reproductions and further details of the coaches themselves and of the early history of mechanical road vehicles will accompany them.